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SECONDARY FRAGMENT IMPACT SENSITIVITY OF VARIOUS MUNITIONS

December 1977

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An experimental program has been completed which provides secondary fragment impact sensitivity data for designers of munition production facilities. The targets tested were 155 mm, 120 mm, 81 mm, and 4.2 inch shells and two models of melt kettles. All target shells depicted the "just filled" condition of the loading operation where the Composition B or TNT is in the molten state. The data shows the threshold initiation conditions of fragment velocity and mass. The threshold conditions are shown to be over

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strongly dependent on the degree of confinement of the explosive or the shell casing geometry. The ratio of the wall thickness to outside diameter is one of the pertinent parameters to correlate the casing geometry with the fragment velocity needed for initiation of the explosive system.

FOREWORD

The research effort described in this report was conducted by IIT Research Institute for ARRADCOM, Manufacturing Division, Dover, New Jersey, under Contract DAAA21-76-C-0141. This program was a continuation of two previous research efforts in secondary fragment impact sensitivity studies.

D. K. Kalkbrenner was IITRI's project manager and received assistance from IITRI staff members, M. Amor, J. Daley, D. Hrdina, J. Mavec, E. Swider and H. Napadensky. The cognizant technical monitors at Picatinny Arsenal were D. Domella, M. Leondi and R. Rindner.

Respectfully submitted,
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An experimental program has been conducted to determine the secondary fragment impact sensitivity of various munitions. The cylindrical concrete fragments used in testing simulated concrete wall fragments broken-up from an accidental explosion. The targets depicted conditions in the explosive loading operation (melt loading) of the munitions production process. The explosive was in a molten state at about 93°C (200°F). The targets that have been tested in this program are:

155 mm (M107A1) Howitzer shell
120 mm M356 (T15E2) cannon shell
81 mm (M362A1) mortar shell
4.2 inch (M329A1) mortar shell
Scaled model of a melt kettle
Modified model of a melt kettle

A sensitivity curve relating the secondary fragment velocity and mass necessary to initiate the explosive system has been determined for the 155 mm, 120 mm, and 81 mm shells filled with Composition B. Not enough data was collected for the 4.2 inch shell filled with TNT to construct the sensitivity curve. However, the data clearly indicates that this munition is more sensitive than any of the other shells tested. The differences in sensitivity are consequences of differing casing geometries. The ratio of casing wall thickness to outside diameter is the pertinent parameter to relate sensitivities of shells subjected to secondary fragment impacts.

The insensitivity of the melt kettle model was proven. However, by removing the protective water jacket that surrounds the explosive, the sensitivity was significantly increased. The tests with the water jacket removed were called the modified melt kettle.

1. INTRODUCTION

The U. S. Army is presently conducting a modernization program to upgrade melt-loading and other munition production facilities. This upgrading includes the modernization of processes, equipment, and improved safety in facility operations. As part of the program, the internal and external structures of production facilities are being assessed for their ability to prevent or limit propagation of an explosive accident. The magnitude of the explosive loading must be determined and the consequences predicted. The structural specifications to resist the explosive loads should reflect the sensitivity of the material in the particular process being analyzed. Specifications based on material sensitivities that are too conservative (overly safe) result in greater costs in materials and construction. Specifications based on liberal sensitivity data (not safe enough) mean personnel and equipment are at greater risk.

The scope of the present research program is focused on the melt loading area. This is the portion of munitions production where a molten explosive is poured into empty shell casings. Only castable explosives are of interest and this includes Composition B and TNT. To limit the propagation of an explosion, the melt loading area is divided up into smaller bays with a limited total amount of explosive in each bay. The concrete wall barriers between bays serve to limit an accidental explosion in one bay from propagating to an adjacent bay.

The concept of post-failure fragment design is employed in this case to predict the mass distribution of fragments. The fragments are the concrete wall pieces broken up by the explosion. Fragments created by the break-up of the concrete structures are called secondary fragments and those created from the break-up of the donor charge casing are called primary fragments. Figure 1 shows the distinction between primary and secondary fragments and donor and acceptor charges.

Analysis methods presently exist for predicting the mass distribution of concrete wall fragments for any loading conditions. What is not known is the sensitivity of the acceptor explosive to impact from secondary fragments. The objective of this research effort was to determine the reaction threshold velocity for various munition items. This report presents results of sensitivity tests conducted to fill the information gap on various acceptor munitions in the melt loading operation.

Two previous research programs on secondary fragment impacts have been completed. The first experiments were carried out on 155 mm Composition B loaded projectiles, RDX slurry in a variety of containers, and black powder in its shipping container (Ref.1). A total of 20 experiments were conducted on the 155 mm projectile impacted with concrete fragments. No reactions were observed in these tests where the Composition B was at ambient temperature. The second research program was designed to provide more specific sensitivity information for the melt loading operation. Tests were conducted on the Composition B filled 155 mm Howitzer in the facing operation, Composition B at 66°C (150°F), and the "just filled" condition, Composition B at 93°C (200°F), (Ref. 2). For the facing operation only one explosion resulted in fourteen tests. For the "just filled" condition, five reactions were observed in twenty-one tests. Additional tests were performed on a model of a melt kettle, but no reactions could be achieved. The results of these two reports highlights the increased sensitivity Composition B exhibits with increasing temperature.

As a logical extension of previous efforts, it was desirable to determine the effects of shell casing on the impact sensitivity of cast explosives (Composition B and TNT). Tests were therefore carried out on 155 mm (M107A1) Howitzers, 120 mm, M356 (T15E2) cannon shells, 81 mm (M362A1) mortars, 4.2 inch (M329A1) mortars, and two variations of scaled models of melt kettles. These targets span a wide range of casing wall thickness. From the results of these tests an assessment can be made of the variation of impact sensitivity with the munition items casing variables. This data will aid in specifying concrete barriers that are safe, yet constructed with minimum costs.

2. EXPERIMENTAL DESIGN

In this chapter, a description is provided of all the targets tested in this program. Originally, all the targets were to be filled with Composition B. However, due to procurement problems, one TNT filled target was substituted. Also in this chapter is a description of the means employed to generate secondary fragment impact conditions and the test procedures adopted for this experimental program.

2.1 Target Description

The most vulnerable conditions in the melt loading operation (with regard to secondary fragment impact) is when the molten explosive has just been poured and is sitting in the shell at an elevated temperature. A loading funnel is used in this operation and the molten explosive sometimes fills the funnel. The munition item in this state we call the "just filled" condition. Figure 2 shows the 155 mm (M107A1) in this state with the loading funnel filled with molten explosive. All target shells tested in this program were representing the "just filled" condition.

Tests were also conducted on another piece of process equipment - the melt kettle. The melt kettle is a water jacketed cylinder from which the explosive is poured into the shells. Hot water is circulated through the jacket surrounding the explosive to keep it molten. A scaled down model of a melt kettle was tested at our Indiana test site. Full scale tests were not possible due to explosive quantity limitations at this range.

A series of tests have been conducted on four different shells and two variations of the melt kettle model. The four shells are:

155 mm (M107A1) Howitzer
120 mm M356 (T15E2) cannon shell
4.2 inch (M329A1) mortar shell
81 mm (M362A1) mortar shell

A picture of each shell without the loading funnel is shown in figures 3, 4, 5 and 6. These shells were selected due to the wide variations in casing thickness.

Pictures with the dimensions of the two melt kettle models are shown in figures 7 and 8. The scaled melt kettles actually tested were surplus from the previous research program. The actual melt kettle dimensions are shown in figure 9.

The scaling method employed resulted in models with greater confinement and therefore less sensitive than the actual melt kettles. This can be seen by looking at the circumferential or hoop stress equation to see what combination of cylinder diameter and thickness will produce the same stress for identical external pressures. The hoop stress is defined as:

$$\sigma = -\frac{PD}{2t}$$

where σ is the stress, $-P$ the external pressure, D the inside cylinder diameter, and t the cylinder wall thickness. For equal stresses to be realized for the same pressure, the diameter to thickness ratio must be the same between the actual melt kettle and the model.

$$\frac{D_a}{t_a} = \frac{D_m}{t_m}$$

where the subscript a designates the actual system and m the scaled model. For the inside cylinder of the actual system:

$$\frac{D_a}{t_a} = \frac{45.72}{0.635} = 72$$

For the scaled model:

$$\frac{D_m}{t_m} = \frac{12.7}{0.340} = 37.3$$

Therefore, the model inside cylinder provides about twice the confinement or protection as compared to the actual system. Also, additional safety is provided in the scaled model with a 6.35 cm (2.5 inch) water jacket around the explosive as compared to only 2.54 cm (1 inch) for the actual kettle. The total length of the model was thought not to be important as long as impact takes place away from the end. Greater energy is required to crush the model at the bottom where the bottom cover is welded. The model length was therefore not scaled but was based on the maximum

allowable volume or weight of explosive that could be tested.

The modified model of the melt kettle was designed to represent a system more vulnerable than the actual system. The diameter to thickness ratio is:

$$\frac{D_{m_m}}{t_{m_m}} = \frac{25.4}{0.340} = 75$$

This is about equal to the actual melt kettle, but the modified model does not have the water jacket to attenuate the impact. The modified model without the water jacket was tested when it was seen that the water jacket effectively reduced the impact sensitivity. The modified model does not in reality represent any actual piece of equipment. The tests were conducted to shed light on the effects of attenuating impact sensitivities by changing the confinement. A summary of the pertinent information for each acceptor target is shown in Table 1.

2.2 Concrete Fragments

Laced reinforced concrete elements are usually used in structures designed to resist the explosive output of high order detonations. The Army manual TM5-1300 (Ref. 3) recommends the concrete standards specified in the ACI Building Code. This is a high early-strength Portland cement (type III) with a minimum strength of 20684 kPa (3000 psi). To minimize the effect of spalling, the size of the aggregate should be limited to less than 2.54 cm (1 inch). The concrete used in this program to simulate wall fragments was a No. 9 Bag mix Portland cement with aggregate size less than 2.54 cm (1 inch). This was poured by a local contractor. The concrete cured in ambient air for at least seven days before being used.

The simulated concrete wall fragments were fabricated into cylindrical shapes with various length to diameter ratios and weights. Figure 10 shows the cardboard into which the concrete was poured. This shape facilitated launching the fragments from the barrel of IITRI's high pressure air gun. The obturator on the back of the cardboard tube was made of plastic and provided a good seal with the air gun barrel. Table 2 lists the nominal sizes and weights of the fragments used in this program.

Table 2

Characteristics of concrete fragments

Fragment weight kg	(lb)	Length/Diameter L/D	Estimated maximum velocity m/sec	(ft/sec)
32	(70)	½	305	(1000)
52	(115)	1	244	(800)
93	(205)	2	183	(600)
184	(405)	4	152	(500)

2.3 Air Gun Launcher

A high pressure air gun was used to launch the cylindrical concrete fragments at the targets. Figure 11 shows the gun's arrangement relative to the targets. The capabilities of the air gun are shown in Figure 12. A maximum chamber pressure of 17237 kPa (2500 psi) is normally selected for safe operation. With this limitation the maximum velocities for the nominal weight of fragments are listed in Table 2. Significant differences between the actual velocity measured and the maximum velocity results from wind effects on the fragment in flight and friction with the gun barrel as the fragment is being propelled out. Aiming the gun was done with a small laser placed in the barrel. The target was then moved to the desired position and the laser removed before firing. An air compressor pumps air into a large holding vessel. Compressed air is then bled into the gun chamber and the pressure transducer. Charging the gun up to the desired pressure sometimes takes about 45 minutes. Firing the gun was also done remotely.

2.4 Test Procedures

Normally, only one test could be conducted per day. This is limited primarily by the time it takes to melt explosives in the shells. The shells for this program were received either empty or with the explosive in the shell along with the supplemental charge, fuze and fin assembly. For the empty shells, the necessary amount of explosive to fill the shell (Table 1) plus about 1.13 kg (2.5 lb) additional per shell to fill the loading funnel was melted. For the shells that came filled, the round was broken down and the supplemental charge, fuze, and fin assembly was destroyed. The shells were then placed in a hot water bath to melt the explosive inside. This normally took about 2 to 3 hours for the larger shells.

During the melting time for the explosive, the air gun was being prepared. The concrete fragments were weighed immediately before placing them in the gun barrel. The weighing scale could be read to plus or minus ½ of one division which means an accuracy of $\pm$ 1.13 kg (2.5 lb).

A wooden test stand was built for each test so that the targets were positioned perpendicular to the oncoming fragment. This is shown in figure 1. The shells were propped-up with a board. A 2.54 cm (1 inch) thick steel witness plate 30.48 cm x 30.48 cm (12 inch by 12 inch) was was placed beneath the target. In cases where the shell had a knob on the bottom surface for attaching the fin assembly, a hole was cut in the witness plate. Normally two targets were placed on the witness plate. This was done to increase the target area and therefore, the probability of achieving a good hit and also to provide additional information as to the degree of reaction.

Fragment velocities were determined from film records of each experiment. A fiducial marker with 30.48 cm (12 inch) increments was placed in the field of view of the camera. Two cameras were used to film the event. One was a high speed Fastax camera operating at about 4000 frames/sec peak. The other was a slower speed Bell and Howell camera operating at about 64 frames/sec. This was used to provide a back-up record in case of a malfunction in the Fastax operation.

Timing, that is, the time relationship between opening the solenoid value on the air gun's high pressure chamber and starting the cameras, was critical for these experiments. The total running time for the Fastax cameras with 30.48 m (100 ft) of film was about 2 sec. It was desirable to catch the event on the last half of the film footage where the camera has reached its maximum speed and is fairly constant. The timing of the camera and gun solenoid is directly related to the expected velocity of the concrete fragment and this in turn is related to the fragment weight and gun chamber pressure. Selecting the timing was a matter of judgement until enough data and experience was accumulated to predict the relationship. Additional uncontrollable factors such as friction between the fragment and the gun barrel, and wind also affect the timing.

Immediately after the shells had been set-up on the test stand, chromel-alumel thermocouples were attached. The surface temperature near the center of the shell was monitored by a thermocouple attached on the surface with fiberglass

tape. The explosive temperature was monitored by dipping the thermocouple wire directly into the center of the molten explosive. The ambient test site temperature was displayed on a strip chart temperature recorder along with the other temperatures. Fiberglass insulation, about 7.62 cm (3 inches) thick, was placed around the shells to reduce heat loss. This was especially important during cold weather and at high gun chamber pressures requiring a long time to bring the gun up to the desired pressure. The fiberglass insulation is of no significance in the impact mechanics.

For the melt kettle tests, a circulating hot water system was constructed. Water was boiled in a large tank with a propane burner. A pump circulated the water through insulated hoses connected to the jacketed melt kettle model.

3. EXPERIMENTAL RESULTS

In this chapter the raw experimental data is presented. This includes post-test observations of fragments and witness plates and the analysis from the film records (velocity calculations, fireball size, location of hit, time and place of initiation). An overall summary of experimental results is included in the Appendix. The first section of this chapter details the methods used to determine the velocity of the concrete fragment. Subsequent sections present results for each target tested.

3.1 Secondary Fragment Velocity Determinations

To calculate the fragment velocity, a time and motion movie projector was used. Velocities were determined from film records by first measuring length of the projected image of the .305 meter (one foot) increments on the fiducial marker. This provides the scaling factor to convert the projected image of the fragments' displacement into actual meters. The number of frames to traverse that displacement was also recorded. The speed of the camera was determined usually from timing marks on the film. The number of timing marks spaced one millisecond apart were counted along with the number of frames over the portion of the film record where the event occured. The fragment velocity could then be calculated from the following equation.

$$\text{Velocity} = S \frac{\Delta x}{N_f} \times n \text{ (meters/sec)}$$

where S is the scaling factor (meters per centimeter), Δx is the measured projected displacement (centimeters), N_f is the number of frames over the measured displacement, and n is the camera film speed (frame/sec).

In some cases if the timing lights did not function or were spaced too close to interpret accurately, another method was employed. The maximum speed of the Fastax camera can be adjusted by regulating the supply voltage to the camera. If the supply is maintained constant, the camera's speed profile (frames per second versus time) should be fairly reproducible. Also, the camera speed versus the number of frames from the start (time zero) should be constant for each test where the supply voltage was the same. Figure 13 was therefore constructed and used to estimate the camera speed in cases where it could not be determined by the method previously described. All that is necessary is to count the number of frames from the start of the film to the point at which impact occurs and then consult figure 13 for the

estimated camera speed.

In cases where Fastax camera coverage was completely inoperable, velocities could be estimated in a similar manner from the back-up slow speed film coverage. In this case camera speed was assumed to be a constant 64 frames/sec.

In a few cases, camera coverage was completely lost. Under these circumstances the velocity was estimated from the gun chamber pressure. By comparing the pressure to previous tests with the same fragment weight and gun pressure, an estimate was made.

3.2 Scaled Melt Kettle Model

The tests on the scaled melt kettles were confirmation tests of a previous research effort (Ref.2). The present tests however, were conducted with the model filled to capacity (15 kg (34 lb)) with molten Composition B. Three out of the six tests performed resulted in good hits (test numbers MKL-1, MKM-2 MKS-3). These three tests were with three different fragment weights, 175, 93 and 33 kg (385, 205 and 73 lb), propelled at the maximum velocities capable for the air gun. No reactions resulted in these tests, which was consistent with previous results. In all cases the model was severely crushed and flattened out. In test MKS-3, the film record shows a spark at impact with the outer cylinder, but at that point no explosive was in the vicinity and so no initiation resulted.

3.3 Modified Melt Kettle Model

Three impact sensitivity tests were performed on the modified melt kettle model. The maximum allowable explosive charge, 23 kg (50 lb) was used in these tests. This amount of explosive charge filled the 25.4 cm (10 inch) diameter cylinder one third full, about 27.9 cm (11 inches) high. The desired impact location was right at the top surface of the explosive.

For the first test (MMS-1), the Composition B was poured, then left to cool to ambient conditions, 27°C (80°F). The smallest concrete fragment was used since it generates the most severe impact conditions with a greater probability of causing a reaction. However, no reaction resulted even though the cylinder was severed in half. Large chunks of Composition B were found post-test and the bottom portion of the cylinder was found with the solid Composition B still in it.

The second test (MMS-2) was conducted with approximately the same fragment weight, but this time the explosive was in the molten state at 97°C (207°F). The fragment velocity was slower for this test, but the impact still caused a low order reaction. The witness plate was slightly warped (approximately 0.32 cm (1/8 inch) indentation) and the wooden test stand was charred. No explosive was found after the test. Two large metal fragments plus the bottom plate were recovered post-test. The high speed movie film showed a bright flash upon impact lasting approximately 0.25 msec.

For the third test (MMM-1), a large fragment, 95 kg (205 lb) impacted the target with the Compostition B molten and this too caused a low order reaction. From the film record it was observed that a fireball, 1.22 to 1.52 meters (4 to 5 ft) in diameter was formed and lasted about 55 msec. It is interesting that only the bottom portion of the cylinder was found post-test since that was where the Composition B existed. It is likely that as the concrete fragment was squeezing the cylinder near the middle, some liquid Composition B was forced to flow to the top. The fragment probably continued to penetrate until it approached the back surface of the cylinder. Initiation likely occured at this point either due to the extrusion process forcing the explosive from the bottom to the top or by pinching the explosive between the collapsing metal surface. Because the fragment penetrated so far, it effectively isolated the top of the cylinder from the bottom and thereby prevented the initiated explosive on top from transmitting to the bottom.

3.4 155 mm Howitzer Shells

Six impact experiments were performed to confirm results from the previous research program (Ref.2). In the tests performed in reference 2, the loading funnels were not filled with explosive as they sometimes are in the actual process. It was conjectured that for impacts at the top of the shell, the collapse of the explosive filled funnel could increase the vulnerability of these munitions. It was planned that the velocities for these tests should be slightly lower than the threshold velocities determined in reference 2. Two tests were conducted with each of three fragment weights: 34, 95 and 186 kg (75, 210 and 410 lb). The estimated threshold velocities at these weights are: 247, 149 m/sec, (810, 490 ft/sec) and somewhat greater than 183 m/sec (600 ft/sec).

The first test (155S-1) for the 34 kg (75 lb) fragment

at 244 m/sec (802 ft/sec) resulted in a high order detonation of the primary target. One large fragment (about ¼ of the shell casing) was recovered and the witness plate was slightly bent. The second target reacted low order. The shell casing was broken into three large fragments and no explosive was left in the shell. From the film it was determined that the concrete fragment impacted right at the shell/funnel interface. This is the desired hit location since it is believed that the squeezing action taking place at the neck of the shell is the most probable mechanism of initiation. Therefore, this is the most vulnerable area of the munition for secondary fragment impacts with the explosive in the molten state. A second test (155S-2) with a 34 kg (75 lb) fragment at a slower velocity did not impact the shell at the desired location. The fragment hit high, and only destroyed the funnel.

The two experiments with the medium weight fragments, 93 and 95 kg (205 and 210 lb) both caused reactions of the explosive. The first (155M-1) was slightly greater than the threshold velocity of 161 m/sec (529 ft/sec) and resulted in a high order detonation of the primary target and low order detonation for the second target. Impact again took place about at the shell/funnel interface. The witness plate was dented about 0.635 cm (¼ inch). No fragments were recovered for the primary target. For the second shell, two large metal strips of the casing and the funnel were found after the test. Film coverage showed a spectacular fireball about 10.7 m (35 ft) in diameter. The second test (155M-2) was at a velocity below the previously determined threshold of 133 m/sec (435 ft/sec) and resulted in a low order detonation of the primary target. Impact was slightly lower than desired. The shell was found split into two large fragments. No damage was inflicted on the witness plate. The second target received minor scratches and was recovered with molten explosive still inside. The low order reaction produced a fireball about 4.9 meters (16 feet) in diameter.

Neither of the two tests conducted with the large concrete fragments, 186 kg (410 lb) resulted in any initiations. The first test (155L-1) did not achieve the desired impact conditions. The fragment hit high and damaged only the explosive funnels. In the second test (155L-2) a good hit was produced just below the top of the shell. The fragment velocity was 145 m/sec (475 ft/sec). The necks of both targets were squeezed shut. The velocities achieved in these two tests for the 186 kg (410 lb) fragments are about the limit of the air gun's capabilities.

3.5 81 mm Mortar Shells

In this section the test data for each concrete fragment weight category is described seperately. The tests were not conducted in the sequence in which they appear in the text that follows.

3.5.1 Nominal Fragment Weight of 34 kg (75 lb).

A total of five experiments have been conducted with fragments in this weight category and only one high order detonation was observed. Three shots did not produce the desired impact conditions - the fragment hit either too high or too low. In tests 81S-1 and 81S-2 only the loading funnels were destroyed. In test 81S-4, the bottom threaded portion of the two target shells were either bent or sheared off.

The two tests that provided useful information were 81S-3 and 81S-5. In tests 81S-3, the calculated velocity was 262 m/sec (858 ft/sec) and no reaction was visible on the film records. This was somewhat suprising since only a few small fragments could be found of the primary target after the test. No damage was done to the witness plate. The second target received only a small dent on the side. In test 81S-5 the fragment was propelled at 276 m/sec (906 ft/sec) and this caused the primary target to react high order. One large metal fragment and numerous small fragments were recovered post-test and the witness plate was warped about 0.635 cm (¼ inch). The second target shell was crushed at the top and the funnel destroyed. Impact took place about at the desired location (shell/funnel interface). It appeared from the film coverage that the edge of the concrete fragment struck the shell first. Initiation was about 1.15 msec after initial contact was made. Initiation, however, appeared to be at the bottom of the shell.

3.5.2 Nominal Fragment Weight of 52 kg (115 lb).

For this fragment weight, four tests were performed with one high order reaction. Tests 81MS-2 and 81MS-4 both hit high on the primary shell, destroying the funnel and crushing the very top of the shell. Neither caused any reaction.

In test 81MS-1 the fragment hit the shell squarely in the center and virtually flattened the shell. No explosive was left in the shell after the test. From the film record, a small puff of black smoke was seen upon impact. Composition B was shot up into the air by the squishing of the

shell. No spark, flame or any additional evidence of a reaction was observed. The fragment velocity was 234 m/sec (768 ft/sec).

Test 81MS-3 at 248 m/sec (813 ft/sec) resulted in a high order detonation of the primary target shell. A few medium size fragments were found and the witness plate beneath the shell was blackened and warped about 0.318 cm (1/8 inch). The film record showed ignition to be at the top of the shell and a fireball formed which lasted about 160 msec. The adjacent second target shell did not receive any damage.

3.5.3 Nominal Fragment Weight of 93 kg (205 lb).

Five tests were performed with the medium size fragment weight category and reactions resulted in three of them.

Tests 81M-3 at 134 m/sec (440 ft/sec) and 81M-5 at 109 m/sec (358 ft/sec) were two tests which did not cause an initiation. For test number 81M-3 impact was about at the center of the shell causing it to be severely crushed. No explosive was left in the shell after the impact. In test 81M-5 at a slower velocity, the fragment hit exactly at the desired location. The shell was squeezed not quite shut at the neck.

Test 81M-4 which resulted in a high order detonation had about the same fragment velocity, 133 m/sec (435 ft/sec) as test 81M-3 which did not initiate. Impact was again right at the shell/funnel interface. One large shell fragment was recovered along with numerous small and large funnel fragments indicating the explosive filled funnel also reacted. The adjacent second target was not damaged. The film of this test shows that the explosive was initiated at the bottom of the shell at about 1.4 msec after the fragments' initial contact. A fireball lasted about 0.13 sec.

For test 81M-2, the fragment velocity was calculated as 163 m/sec (535 ft/sec) and this caused a high order detonation in both the primary and secondary target shells. A few large metal casing fragments and many smaller ones were recovered.

Similar results were obtained in test 81M-1 with a fragment velocity of 186 m/sec (611 ft/sec). The impact in this case was such that the secondary target shell received the main impact causing it to react high order. Numerous medium to small metal fragments were found. The other shell detonated low order. The bottom portion of the shell appeared to

have been blown out and the top portion squeezed shut. Many funnel fragments were recovered which could indicate the explosive in the funnel reacted.

3.5.4 Nominal Fragment Weight of 181 kg (400 lb).

For this weight class, four shots were performed with a detonation in one of them. The fragment velocity in test 81L-4, 139 m/sec (457 ft/sec) was the highest of the four tests and this did not cause an initiation. The fragment hit off to the side causing only slight damage to the neck of the shell and funnel.

In test 81L-2, the velocity was slower, 143 m/sec (470 ft/sec) but impact was at about the center of the shell. Only the threaded portion at the bottom of the shell was recovered after the high order reaction. The adjacent shell received only a scratch and did not initiate. Impact occured very early on the film record and this made it very difficult to interpret.

Two additional tests at lower velocities did not cause any reactions. The concrete fragment in test 81L-3 impacted the shell at slightly below the desired location at a velocity of 109 m/sec (359 ft/sec). The shells were recovered with about 1/3 of the Composition B still in them. In test 81L-1, the fragment velocity was about 137 m/sec (449 ft/sec) but impact was much too high, inflicting damage only to the funnel.

3.6 120 mm Cannon Shells

3.6.1 Nominal Fragment Weight of 34 kg (75 lb).

Six shots were performed for this fragment weight with burning reactions resulting in two of the shots. In one test (120S-4) the gun was misaligned and the fragment completely missed the target. No reactions resulted in the following three tests at the velocities indicated:

120S-1	269 m/sec	(882 ft/sec)
120S-6	207 m/sec	(679 ft/sec)
120S-5	178 m/sec	(585 ft/sec)

In tests 120S-1 and 120S-6, impact was at the top of the shell and caused the shell to be squeezed and the funnel destroyed. In test 120S-5, the fragment hit the center of the shell making a dent about 2.54 cm (1 inch) deep. The fragment velocity could not be interpreted from the film

record since the event occured too early on the film. However, since the weight and gun pressure were the same as in test 120S-4, the velocity for this test was assumed to be the same as in test 120-S-5.

The two shots that resulted in burning reactions are listed below:

120S-2	301 m/sec	(988 ft/sec)
120S-3	244 m/sec	(800 ft/sec)

No film coverage was obtained for test 120S-3 because of a severed electrical line. The velocity was interpolated from the air gun chamber pressure and velocities calculated from previous tests. The evidence that a burning reaction had taken place is the charred witness plate and wooden test stand. Funnel fragments were found post-test, but the shell was not damaged at all. In fact, the shell was recovered still half filled with liquid Composition B. It appears that only the explosive filled loading funnel was involved in the impact and in some manner initiated the explosive as it was being crushed. The reaction, however, did not propagate to the explosive in the shell.

In another test (120S-2) at a higher velocity, film coverage was available. Impact was right at the shell/funnel connection. A flash lasting about 1 msec resulted upon impact. The shell appeared to be cracked in half rather than fragmented by a blast. No damage was done to the witness plate nor the adjacent second target.

3.6.2 Nominal Fragment Weight of 52 kg (115 lb).

A total of four tests were conducted with this fragment weight with one of these resulting in a high order detonation (120MS-1, 243 m/sec (797 ft.sec)). For this shot initiation was about 5 msec after initial impact. Small to medium sized fragments were found after the test and the witness plate was slightly dented and gouged. The second target received only minor scratches and did not react. Impact was at the neck of the shell and funnel.

For the other three tests at this weight: shot 120MS-2 hit slightly high and sheared the funnel off; shot 120MS-3 hit lower causing the shell to be somewhat squeezed and elongated; shot 120MS-4 achieved a good impact at the neck of the shell but did not cause a reaction at 220 m/sec (721 ft/sec).

3.6.3 Nominal Fragment Weight of 93 kg (205 lb).

At this weight category, the 120 mm shell could not be detonated in four tests with a maximum fragment velocity of 199 m/sec (652 ft/sec). Good impacts however, were achieved in only two of the shots (120M-2 and 120M-4) at 180 and 182 m/sec (591 and 596 ft/sec). In the other two shots impact was slightly high and squeezed the neck of the shell and destroyed the funnel.

3.6.4 Nominal Fragment Weight of 184 kg (405 lb).

Out of four shots for this weight class, one burning reaction resulted at a velocity of about 109 m/sec (358 ft/sec). In this shot, (120L-2) initiation was at the ground away from the point of impact. The top 1/3 of the shell was broken off and no Composition B was found in the shell afterwards. Impact was at the neck of the shell.

Two other shots at higher velocities and one at a lower velocity did not cause any explosive reaction.

3.7 4.2 inch Mortar Shells

3.7.1 Nominal Fragment Weight of 32 kg (70 lb).

Two high order detonations resulted out of four shots with the 32 kg (70 lb) secondary fragments. The velocity for shot 4.2S-1 was 273 m/sec (896 ft/sec), and 226 m/sec (741 ft/sec) for shot 4.2S-3. The velocities where no reactions occured were 242 m/sec (793 ft/sec) for shot 4.2S-2 and 127 m/sec (417 ft/sec) for shot 4.2S-4. The impact location for shot 4.2S-2 was low, however, the bottom half of the shell was thoroughly flattened. Less severe crushing occurred in shot 4.2S-4 at a slower velocity.

In test number 4.2S-1 where a detonation resulted, only a few small to medium size fragments were recovered. A fireball 4.9 meters (16 ft) in diameter lasted about 360 msec. Similar fragmentation resulted in test 4.2S-3 along with charring of a wooden test stand. Initiation in this test occured about 0.5 msec after initial contact with the shell.

3.7.2 Nominal Fragment Weight of 52 kg (115 lb).

The four tests conducted at this weight all resulted in high order detonations. The velocities ranged from 123 to 238 m/sec (404 to 782 ft/sec).

Shot number 4.2MS-1 had a fragment velocity of 236 m/sec

(774 ft/sec) and hit right at the shell funnel joint. Small to medium sized fragments were found post-test. A fireball 3.4 meters (11 feet) in diameter formed from the high order detonation. For shot 4.2MS-2 at 201 m/sec (659 ft/sec), the hit location was about the same but the fragments were much larger. Initiation took place right at the crack between the shell and funnel and occurred 1.6 msec after initial contact. A fireball about 4.0 meters (13 feet) in diameter was created which lasted 0.2 seconds. In shot 4.2MS-4, the velocity was 146 m/sec (480 ft/sec) and the hit location more towards the center of the shell. The high order detonation occurred 12 msec after impact and was initiated by impact with the ground. Test 4.2MS-3 had the lowest velocity of the four shots, 123 m/sec (404 ft/sec). One large metal fragment, about 3/4 of the casing, and a few smaller ones were recovered. The casing appeared to be torn or ripped apart rather than blasted. The wooden test stand was burnt. Initiation took place at the interface between the funnel and shell and occurred 0.35 msec after initial contact. The fireball created was about 4.3 meters (14 feet) in diameter.

3.7.3 Nominal Fragment Weight of 91 kg (200 lb).

The four tests conducted at this weight resulted in two high order detonations and one burning reaction. The shot that did not cause a reaction (4.2M-1) hit slightly off to the right, crushing the top of the shell and funnel. The molten TNT was splattered around the test area.

In shot 4.2M-2, the fragment velocity was 168 m/sec (551 ft/sec) and the hit location slightly high. The shell was recovered with the top 10.2 cm (4 inches) squeezed shut and some TNT left inside. The film record showed a small flash and black smoke cloud created about 1.5 msec after impact. The initiation was at the top of the shell where the funnel joins it. The reaction did not propagate to the rest of the explosive in the shell. This reaction was called a burn.

The velocity for shot 4.2M-3 was calculated as 161 m/sec (528 ft/sec) and caused a high order detonation. Impact took place at the desired location and only small fragments were recovered post-test. Initiation was at the crack between the top of the shell and the shoulder on the funnel. Initiation happened 0.48 msec after impact.

The last shot for this weight category (4.2M-4) was at 97 m/sec (318 ft/sec) and the same hit location. Only a few small fragments were recovered after the high order detonation. Initiation occured 1.5 msec after contact and appeared to start at two locations simultaneously: one at the top of the funnel and another at the bottom of the shell.

3.7.4 Nominal Fragment Weight of 181 kg (400 lb).

Only one test was conducted with this size fragment. The result was a high order detonation for a fragment velocity of 143 m/sec (470 ft/sec). The test stand was burnt and medium size metal fragments were found post-test. Initiation again appeared to be at two seperate points - at the top of the funnel and at the junction between the funnel and shell. Initiation started 0.6 msec after contact.

4. ANALYSIS OF DATA

In this chapter some fundamental relationships between the variables in a secondary fragment impact experiment will be presented. As an obvious first consideration, the variables external to the details of the actual impact (i.e., fragment mass and velocity) will be related. This establishes the available kinetic energy and momentum but says nothing of the dynamics of the impact, the efficiency of the energy transfer process or the rate of energy transfer to the explosive. These variables are in some way related to the properties and geometries of the shell casing, explosive, and fragment. The importance of the location of impact will also be discussed since various casing geometries will react or deform differently depending on where the loading is applied.

4.1 Mass-Velocity Sensitivity Curves

The boundary velocity is defined as the fragment velocity necessary to initiate a high order detonation in the acceptor explosive. If enough data could be collected, the boundary velocity could be determined with various probability levels.

Fragment velocity versus fragment mass data has been plotted to depict the targets' sensitivity to secondary fragment impact stimuli. The boundary velocity representing the estimated threshold initiation conditions was determined for the 155 mm, 120 mm, and 81 mm shells. Not enough data has been collected for the 4.2 inch shells and scaled melt kettle models to determine the boundary velocity curve.

The plots of the data are shown in figures 14 through 19. The pertinent data to determine the boundary velocity is shown in Table 3. The data clearly indicates that the 4.2 inch TNT filled mortar shell is more sensitive than any of the other Composition B filled targets. The 155 mm, 120 mm and 81 mm shells juggle positions of relative sensitivity depending on the weight category. The other observation of the data in Table 3 is that neither momentum nor kinetic energy provide reliable information to predict sensitivities. This was also apparent in the data of reference 2. It was evident from the post-test observations of partially damaged concrete fragments that in some cases the fragment transfers a portion of its momentum and energy to the target then continues on relatively unscathed. This means that most of the available energy is not transferred

to the target. An assessment of the percentage of available momentum or energy transferred for the target could not be made with the available evidence.

The data points plotted in the sensitivity curves are considered to be equal. That is, the details of each experiment were neglected and just the net result taken. No attempt was made to weigh any points with regard to where the fragment hit or the severity of the impact. Impacts high on the shell are known to increase the probability of initiation.

4.2 Confinement Effects

The effect of the shell casing or confinement on the mass/velocity sensitivity data will be discussed in this section. In an impact experiment the casing properties, primarily material strength, determine how much of the incoming energy will be needed to crush or penetrate the casing and therefore, the amount of energy transferred to the explosive.

For the melt kettle testing, two different models were tested: one representing a system believed to be less sensitive than the actual system, and another model representing a more sensitive case. As discussed earlier, the cylindrical casing outside diameter to thickness ratio provides an indicator of relative strength to withstand external pressure. These values are listed below:

Actual system based on internal tube diameter D/t	= 72
Actual system based on external tube diameter	= 53.3
Melt kettle model based on internal tube dia.	= 37.3
Modified model (without water jacket)	= 75

If it is assumed that the boundary velocity is directly proportional to the ratio D/t, then some method could be devised to proportion the model data to predict actual system conditions. If this is true, then the ratio of D/t will provide the necessary factor. Comparing the first melt kettle model with a 6.35 centimeter (2½ inch) water jacket to the actual system gives:

$$\frac{(D/t)\text{actual}}{(D/t)\text{model}} = \frac{72}{37.3} = 1.930$$

The actual system velocities can now be scaled up from the model data: V actual = 1.930 V model. This has been done to the data in Table 4 for the melt kettle. Two points should be emphasized. First, the model had a 6.35 centimeter (2½ inch) water jacket whereas the actual melt kettle has only a 2.54 centimeter (1 inch) jacket. This has the effect of

making the scaling factor (1.930) somewhat too high. Secondly, since no reactions were achieved, the so-called actual velocities just calculated would represent the minimum expected boundary velocities. Therefore, the scaling factor may be somewhat low. This scaling scheme should only be regarded as an estimate since no evidence has been collected in this program to confirm that the diameter to thickness ratio of the casing around explosives is directly proportional to the boundary velocity necessary to initiate the explosive.

Table 4

Melt kettle model impact data
velocity scaling to actual system

Fragment weight kg (lb)	Impact velocity m/sec (ft/sec)	Results*	Scaled velocity m/sec (ft/sec)
23 (51)	257 (843)	NR	496 (1627)
33 (73)	259 (850)	NR	500 (1640)
84 (185)	199 (653)	NR	384 (1260)
93 (205)	176 (577)	NR	340 (1115)
170 (375)	148 (486)	NR	286 (938)
175 (386)	123 (404)	NR	237 (778)

* NR = No Reaction

The modified melt kettle obviously proved to be more sensitive to secondary fragment impact than the first melt kettle model. Removal of the water jacket therefore, increased the sensitivity of this system, but the amount of increase is difficult to evaluate with the limited data.

For the other target shells, some of the pertinent data concerning the casings are shown in Table 1. The 4.2 inch mortar shell is seen to have the smallest thickness to diameter ratio, meaning it will provide the least amount of resistance to external pressure. Even though a sensitivity curve could not be constructed yet for the 4.2 inch shell, the impact data still appears to confirm the greater vulnerability of this munition item compared to the others. The thickness to diameter ratio is therefore, a dominant factor in secondary fragment impact tests.

The t/D ratios indicated in Table 1 are based on the wall thickness at the maximum diameter of the shell. It might be more accurate to choose the minimum t/D ratio over the cross sectional area the fragment impacts. This has been done for the 81 mm test series data (Table 5). The variations of the t/D was not significant (.0630 to .0693) except in one shot (81MS-2, t/D = 0.218). The small variation of the t/D could not be correlated to any effect on the threshold initiation conditions. Therefore, choosing a reference thickness to diameter at the maximum diameter of the shell appears adequate.

On a more analytical level, the t/D ratio is also seen to be an important factor in studying cylinders and the stresses that result from external pressure. Elasticity theory reveals that for cylinders having internal diameter to thickness ratios greater than 10, the pressure is related to the stress and the t/D:

$$p \alpha (t/D)^1$$

That is, the pressure (p) is directly proportional to the t/D ratio. Elasticity theory also shows that the collapsing pressure (P_c) is related to the t/D ratio to the third power (Ref.4):

$$P_c \ \alpha (t/D)^3$$

Therefore, if the impact velocity is proportional to the pressure developed on the shells, then the velocity should be related to the t/D:

$$V \ \alpha (t/D)^a$$

where the exponent, a, would be between 1 and 3.

The effect of confinement for primary fragment impact has been investigated in reference 5. In this case the boundary velocity was related to the fragment mass, the casing thickness, and the type of explosive. The derived equation follows.

$$V_s^2 = \frac{K\, e^{(5.37\ t/m^{1/3})}}{m^{2/3}(1 + 3.3\ t/m^{1/3})}$$

V_s = boundary velocity (ft/sec)
m = primary fragment mass (ounces)
t = acceptor casing thickness (inches)
K = experimentally determined explosive sensitivity constant

Numerous shells and explosives were investigated. The explosive sensitivity constants for Composition B and TNT were determined to be:

$K = 4.148\times10^6$ Comp. B (RDX/TNT, 60/40)
$K = 16.303\times10^6$ TNT

Figure 20 highlights the difference between primary and secondary fragment impacts.

Certain assumptions built into the derivation of the primary fragment correlation make it impossible to adopt a similar formulation for secondary fragment impacts. First, the mechanism of initiation is believed to be quite different. For primary fragments, the casing is first penetrated, then the fragment impacts the explosive causing initiation. Initiation is on the order of micro-seconds after impact. In secondary fragment impacts, the initiation is conjectured to be by extruding or pinching the explosive as the shell collapses. In this case, initiation occurs a few milliseconds after impact. Secondly, the fragment shapes are much different. Primary fragments have a small projected area of impact whereas secondary fragments may impact the total area of the target. Thirdly, primary fragments are of the same material (mild steel) as the casing whereas secondary fragments are not.

4.3 Explosive Properties

It is reasoned that the sensitivity of an explosive, that is, its propensity to initiate by a certain stimuli, will be affected by its geometry and thermodynamic state. This was clearly shown in reference 1 and 2 where the secondary fragment impact sensitivity of Composition B filled 155 mm shells, increased with increasing temperatures of the explosive. The explosive was more sensitive at or above its recrystallization temperature ∿ 77°C (170°F) for Composition B. The data collected in this research effort for

secondary fragment impacts of TNT and Composition B filled shells also points to the fact that the properties of the explosive effect the initiation level. The TNT filled 4.2 inch mortar shells were more sensitive than the other various shells, tested in this program, filled with Composition B. However, the Composition B filled shells were a different geometry and had greater casing protection. From small scale impact tests using the Bureau of Mines apparatus, the TNT should be less sensitive than the Composition B.

95-100 cm drop weight height for TNT
75 cm drop weight height for Composition B

It has been assumed in the present tests that the thermodynamic state of the explosive is the same between tests. This may be questionable since the temperature of the explosive did vary 64 - 97° C (148 - 207°F) between tests and a phase change occurs at about 77°C (170°F) for Composition B. The thermodynamic state is also important in that the manner in which the explosive deforms upon impact may determine the degree of viscons heating. Consequently, as some theorize, local hot spots could develop to initiate the explosive. This is especially important in secondary fragment impacts where it is conjectured that the extrusion of the explosive is the most probable mechanism of initiation.

The weight of the explosive is an additional consideration. It is well known that a critical mass exists above which an initiation will propagate to a high order detonation and below which a low order or less severe reaction results. The explosive to shell casing weight ratio (E/C) (Table 1) has been shown to be a convenient parameter characterizing the explosive output of a munition item. The E/C is usually associated with the donor explosive system.

The total mass of the acceptor explosive system (explosive plus casing) may be important for the following reason. The mass of the system provides an inertial force to resist the impact force trying to accelerate it. It is these two counteracting forces which to a certain extent determines how much and how fast the shell will be crushed.

The geometry of the explosive is another factor which could affect the details of how the explosive deforms upon impact. Just how a stress wave propagates through the explosive and how it is reflected from the surface is geometry dependant.

The net affect of all these factors is as yet not predictable with any precision. The derivation of the sensitivity equation in reference 5 attempted to account for the explosive by dumping all these effects into an "explosive sensitivity constant" (K). This method, however, obscures any physical significance this constant might have.

At present, there does not exist enough data to take into account the effects of explosives properties. Tests should be conducted on identical shell casings but with various explosive fillers to assist in incorporating this variable into a secondary fragment impact sensitivity model.

4.4 Secondary Fragment Properties

There appears to be two important characteristics of secondary fragments other than the weight and velocity which may affect sensitivity: strength and geometry. In an impact experiment it is the strength of the fragment pitted against the strength of the casing, which controls the energy transferred to the explosives and the work done on the casing to extrude the molten explosive. A brittle fragment upon initial contact may fracture into numerous smaller fragments and thereby have a lower proability of penetration and initiation of the explosive.

Looking at the concrete fragment as a structural member, compressive strength for impact loading is about 1.5 times greater than the static strength. Loading rates greater than 68948 kPa/sec (10,000 psi/sec) are considered to be impact loads (Ref. 6). It is estimated that the compressive strength for a 30.48 centimeter (12 inch) diameter cylinder is between 13790 to 34474 kPa (2000 to 5000) psi for concrete cured between 7 and 28 days (47% to 60% water/concrete) from reference 6. The specific weight for the concrete used in the present experiments is about 2.85×10^3 kg/m^3 (178 lb/ft^3).

In primary fragment impacts, the projected area of the fragment is an important parameter which determines the available energy per unit area. In this case, the fragment dimension is small compared to the radius of curvature of the cylindrical shell. This allows making the simplification that the fragment impacts a flat plate and transfers all its momentum to the plate. For secondary fragment impacts, the fragment area is large compared to the projected area of the target. The assumption cannot be made that the concrete fragment is impacting all its momentum to the shell. Therefore, the energy density based on the impact area will not be important.

5. CONCLUSIONS AND RECOMMENDATIONS

The objective of this research program was to obtain secondary fragment impact sensitivity data of various munitions. Experimental data has been collected on the 155 mm (M107A1) Howitzer, 120 mm, M356 (T15E2) cannon shell, 81 mm (M362A1) mortar shell, 4.2 inch (M329A1) mortar shell, and two scaled process equipment models of a melt kettle. The shells with the loading funnels in place represented the "just filled" condition of the melt loading munition production stage. The explosive at this point is in the molten state around 93°C (200°F). For these conditions, secondary fragment velocity versus mass sensitivity curves were constructed for the 155 mm, 120 mm, and 81 mm shells, Composition B filled. Not enough data has been collected on the 4.2 inch mortar shell TNT filled to determine the sensitivity curve. However, it is still apparent that the TNT filled shell is more sensitive than any of the Composition B filled shells tested. This is a direct consequence of differences in the shell casing geometries.

The following parameters were held reasonably constant for each test:

Thermodynamic state of explosive 64   97°C (148   207°F)
Shell casing material strength properties (all mild steel)
Secondary concrete fragment geometry and strength properties (all cylindrically shaped, L/D varied)

The parameters that were variable included:

Secondary fragment mass and velocity
Shell casing geometry
Impact location on the shell
Explosive (only two explosives were tested: Composition B and TNT)

The data collected thus far is inconclusive in relating sensitivity to shell casing geometry in a quantifiable manner. It is thought that the shell casing wall thickness to outside diameter ratio is the pertinent geometrical factor to be related to the secondary fragment impact velocity and mass. It is further reasoned that the boundary velocity should be related to the thickness to diameter ratio to a power between one and three:

$$V \; \alpha (t/D)^{1 \rightarrow 3}$$

It is recommended that additional tests be conducted to substantiate the above equation form. It is also recommended that tests be conducted on the same or similar shells as tested in this program but with other explosive fillers. This will delineate the effect the explosive has on the munition's sensitivity to secondary fragment impact.

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Table 1

Acceptor targets of secondary fragment impact tests

Target	Explosive weight kg	(lb)	Casing weight kg	(lb)	Wall thickness at maximum diameter mm	(in)	Explosive/ case weight	Wall thickness/ maximum diameter
155 mm (M107A1) Howitzer	7.0 Composition B	(15)	36.2	(80)	18.0	(.709)	0.19	0.116
120 mm, M356 (T15E3) cannon	3.6 Composition B	(8)	18.2	(40)	15.1	(.594)	0.20	0.126
4.2 in. (M329A1) mortar	3.5 TNT	(8)	6.8	(15)	6.0	(.236)	0.51	0.056
81 mm (M3629A1) mortar	0.95 Composition B	(2)	2.23	(5)	5.6	(.220)	0.43	0.069
Scaled melt kettle model 6.35 cm (2.5 in.) water jacket	15.5 Composition B	(34)	23.4	(52)		-	0.66	-
Modified melt kettle (no water jacket, 25.4 cm (10 in.) O. D. cylinder	22.7 Composition B	(50)	14.1	(31)	3.4	(.133)	1.61	0.013

Table 3

Secondary fragment velocity/mass data

Fragment weight kg	(lb)	Boundary velocity m/sec	(ft/sec)	Momentum N-sec	(slug-ft/sec)	Kinetic energy ($Jx10^6$)	($ft-lb_f x10^6$)
Melt kettle model							
23	(50)	>257	(>843)	-	-	-	-
33	(51)	>259	(>850)	-	-	-	-
82	(181)	>172	(>564)	-	-	-	-
93	(205)	>176	(>577)	-	-	-	-
170	(375)	>148	(>486)	-	-	-	-
175	(386)	>123	(>404)	-	-	-	-
Modified melt kettle model							
34	(75)	262	(860)	8908	(2003)	1.167	(0.861)
93	(205)	173	(568)	16089	(3616)	1.392	(1.027)
155 mm (M107A1) (present data and reference 2 data)							
22.7	(50)	335	(1099)	7605	(1707)	1.274	(0.938)
24.3	(54)	325	(1066)	7898	(1788)	1.283	(0.953)
34	(75)	244	(801)	8296	(1866)	1.012	(0.747)
34	(75)	216	(709)	7344	(1651)	0.793	(0.585)
93	(205)	161	(528)	14973	(3361)	1.205	(0.887)
95	(209)	133	(436)	12635	(2830)	0.840	(0.617)
170	(375)	154	(505)	26180	(5881)	2.016	(1.485)
170	(375)	143	(469)	24310	(5462)	1.738	(1.281)

Table 3 (Continued)

Secondary fragment velocity/mass data

Fragment weight kg	(lb)	Boundary velocity m/sec	(ft/sec)	Momentum N-sec	(slug-ft/sec)	Kinetic energy $(J \times 10^6)$	$(ft\text{-}lb_f \times 10^6)$
120 mm (M356)(T15E2)							
32	(71)	269	(883)	8608	(1947)	1.158	(0.860)
30	(66)	207	(679)	6210	(1392)	0.643	(0.472)
51	(112)	243	(797)	12393	(2772)	1.505	(1.105)
52	(115)	220	(722)	11440	(2579)	1.258	(0.931)
93	(205)	199	(653)	18507	(4157)	1.841	(1.357)
184	(406)	109	(358)	20056	(4514)	1.093	(0.808)
184	(406)	149	(489)	27416	(6166)	2.042	(1.508)
81 mm (M362A1)							
32	(71)	276	(906)	8832	(1998)	1.219	(0.905)
34	(75)	262	(860)	8908	(2003)	1.167	(0.861)
52	(115)	248	(814)	12896	(2907)	1.599	(1.183)
52	(115)	234	(768)	12168	(2743)	1.424	(1.053)
93	(205)	133	(436)	12369	(2776)	0.823	(0.605)
91	(201)	109	(358)	9919	(2235)	0.541	(0.400)
184	(406)	143	(469)	26312	(5913)	1.881	(1.387)
177	(390)	109	(358)	19293	(4336)	1.051	(0.776)
4.2 inch (M329A1)							
30	(66)	226	(741)	6780	(1519)	0.766	(0.563)
30	(66)	127	(417)	3810	(855)	0.242	(0.178)
51	(112)	<123	(<404)	-	-	-	-
91	(201)	<97	(<318)	-	-	-	-
182	(401)	<143	(<469)	-	-	-	-

Table 5

Secondary fragemnt impact
81 mm (M362A1) (mortar shell) test data

Shot number	Fragment weight kg	(lb)	Fragment velocity m/sec	(ft/sec)	(t/D) min over impact area	Results*
81S-2	33	(73)	284	(932)	-	NR
81S-5	32	(70)	276	(906)	.0693	HO
81S-4	34	(75)	263	(864)	.0635	NR
81S-3	34	(75)	262	(858)	.0630	NR
81S-1	34	(75)	260	(853)	-	NR
81MS-3	52	(115)	248	(813)	.0630	HO
81MS-1	52	(115)	234	(768)	.0630	NR
81MS-4	52	(115)	232	(760)	.0693	NR
81MS-2	55	(120)	214	(703)	.2180	NR
81M-1	93	(205)	186	(611)	.0693	HO
81M-2	95	(210)	163	(535)	.0630	HO
81M-3	93	(205)	134	(440)	.0630	NR
81M-4	93	(205)	133	(435)	.0630	HO
81M-5	91	(200)	109	(358)	.0630	NR
81L-4	181	(400)	139	(457)	.0693	NR
81L-1	182	(400)	137	(449)	-	NR
81L-3	177	(390)	109	(359)	.0630	NR
81L-2	184	(405)	143	(470)	.0630	HO

At maximum diameter: t/D=0.0690

*NR = No Reaction
HO = High Order Detonation

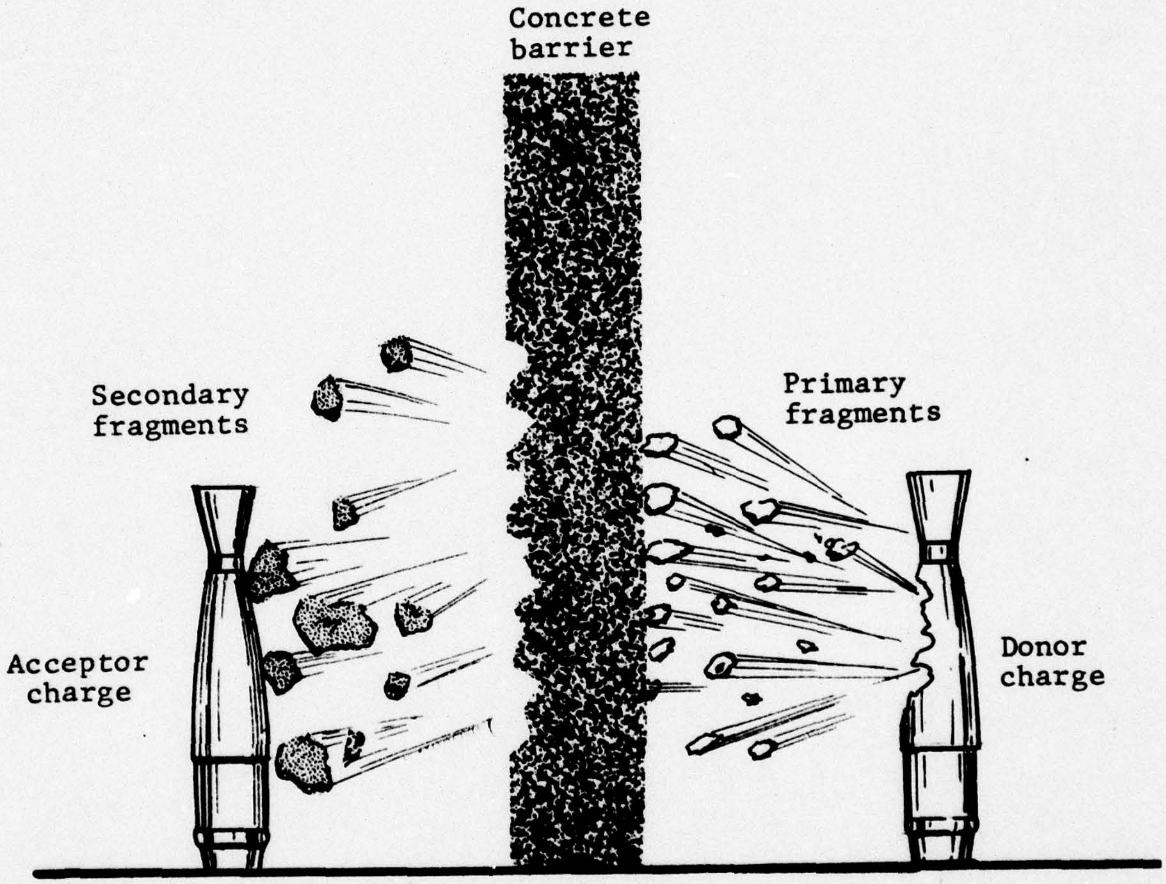


Fig 1 Schematic of secondary fragment impact

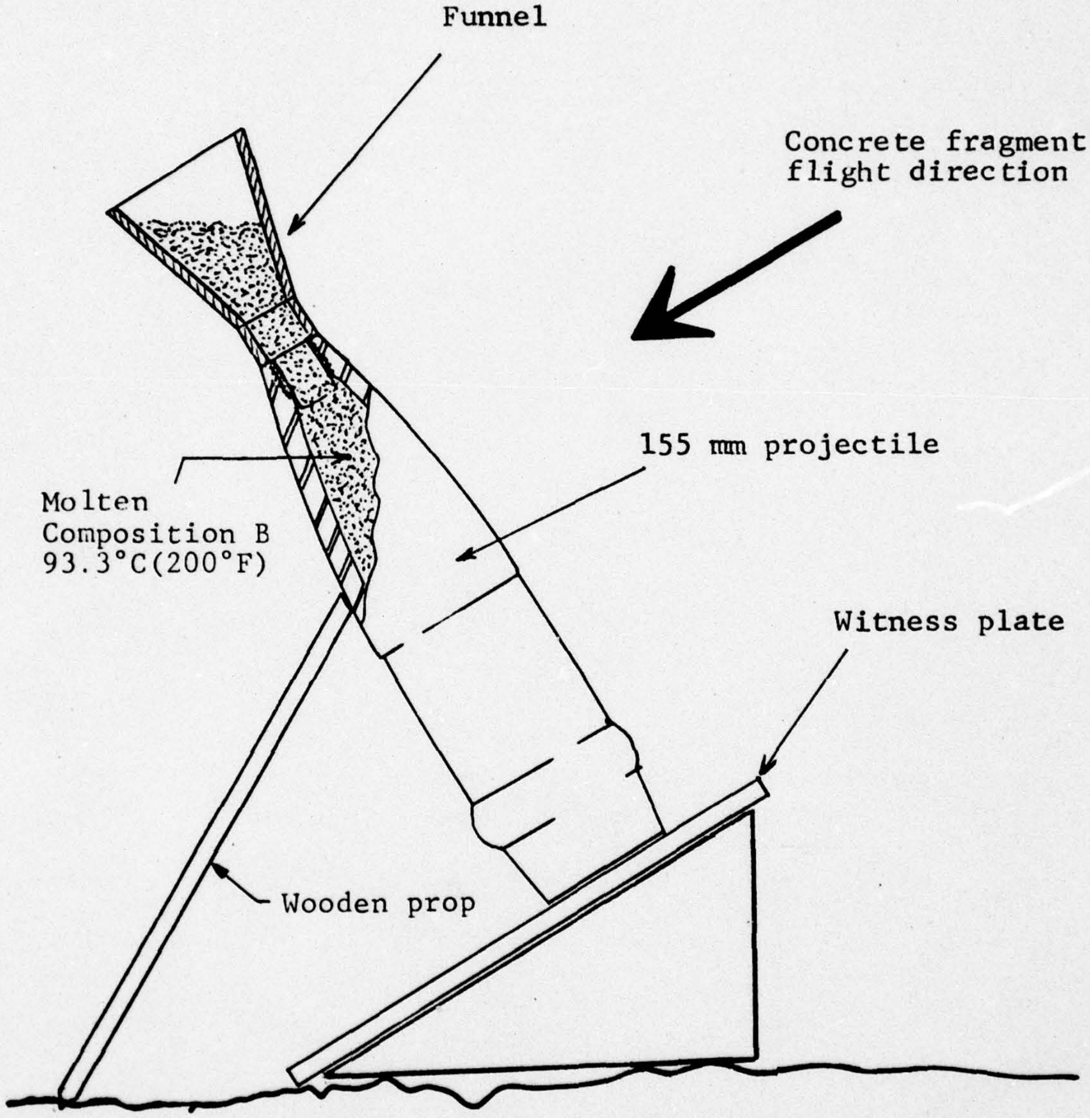


Fig 2 Test setup "just filled" configuration

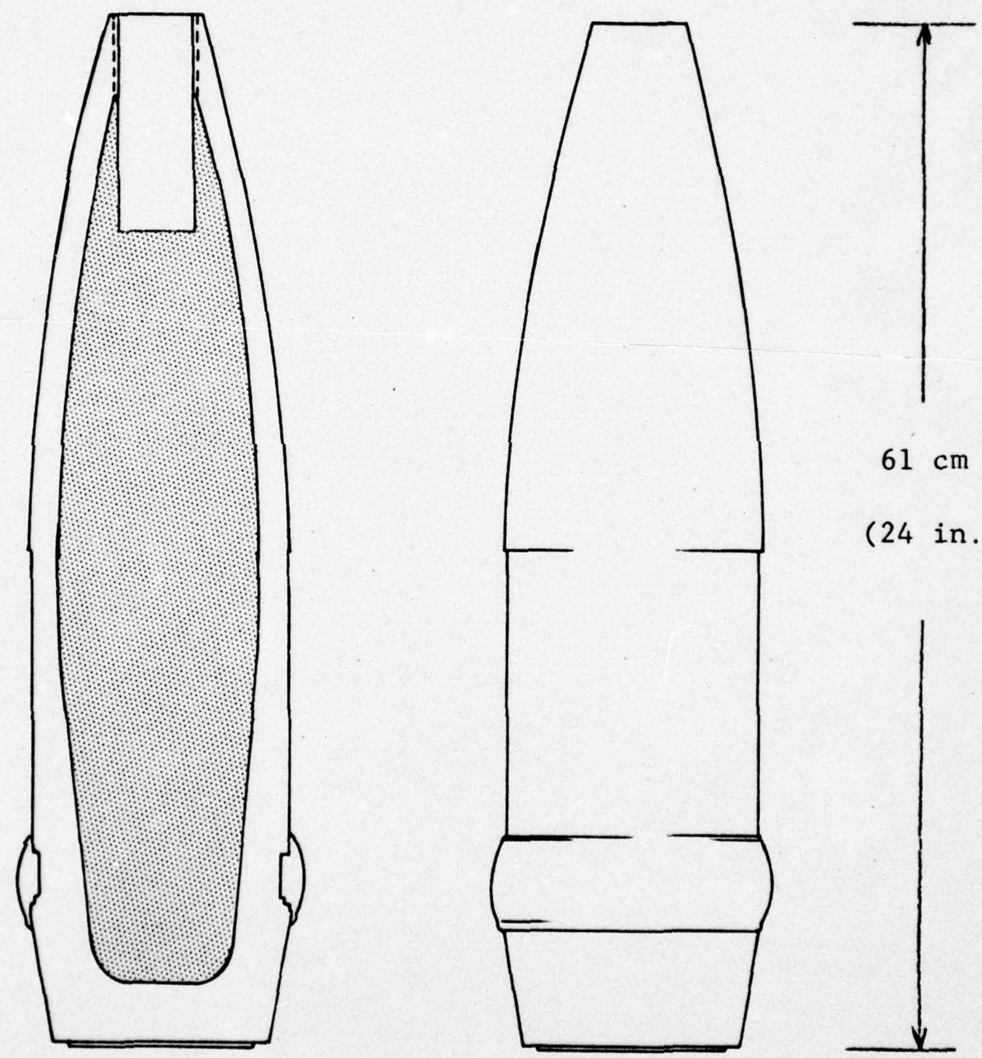


Fig 3 155 mm Howitzer projectile (M-107A1)

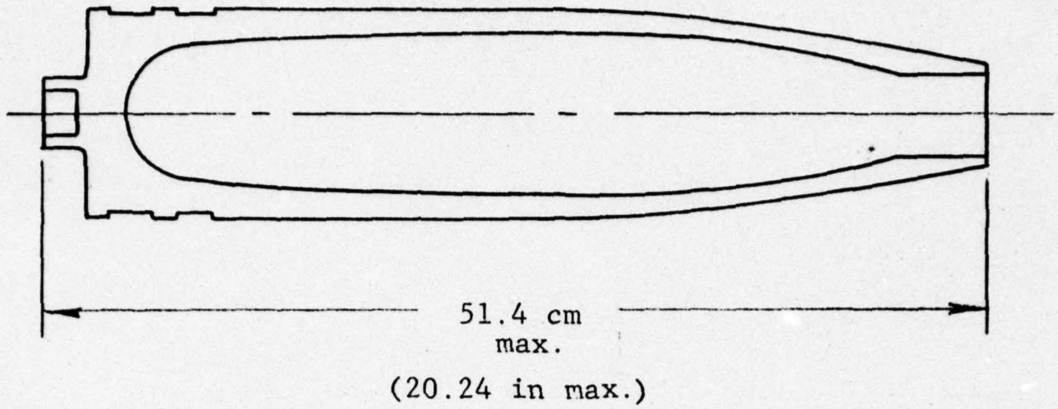


Fig 4 120 mm, M356 (T15E3) cannon projectile

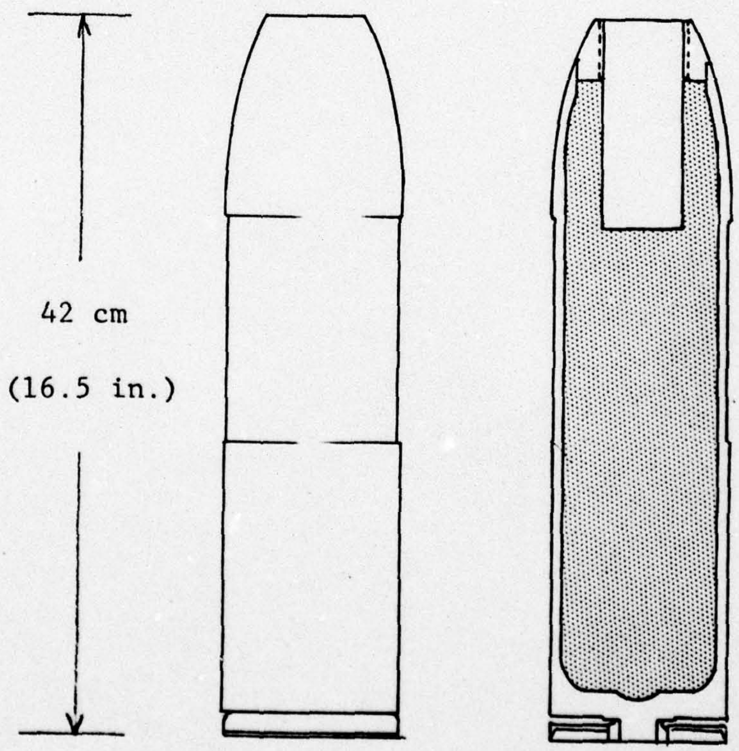


Fig 5 4.2 inch mortar projectile (M329A1)

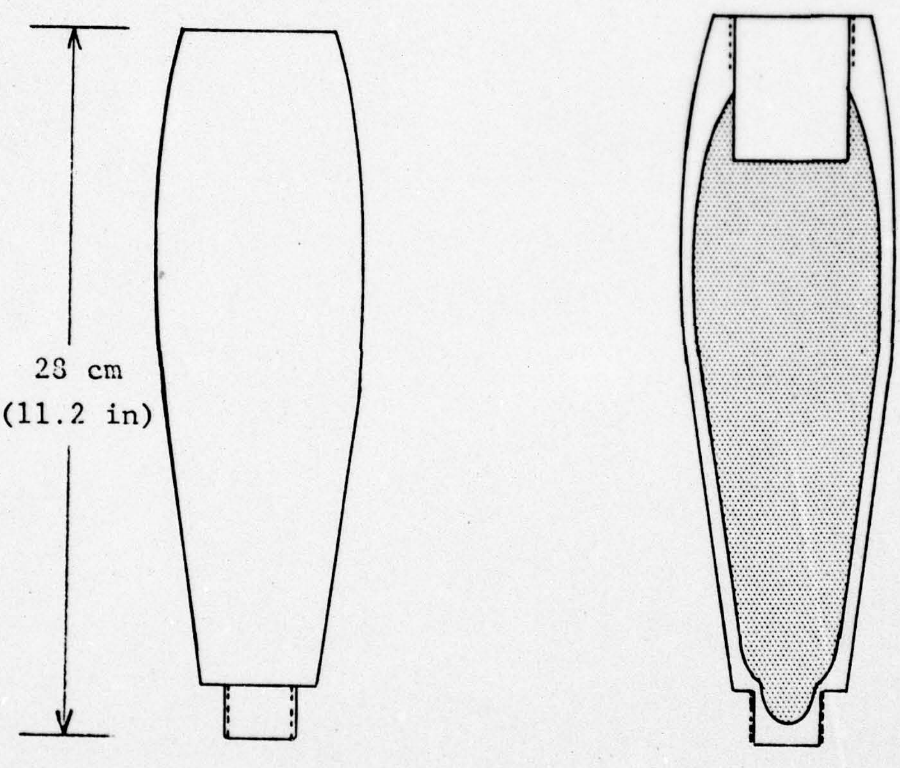


Fig 6 81 mm mortar projectile (M-362A1)

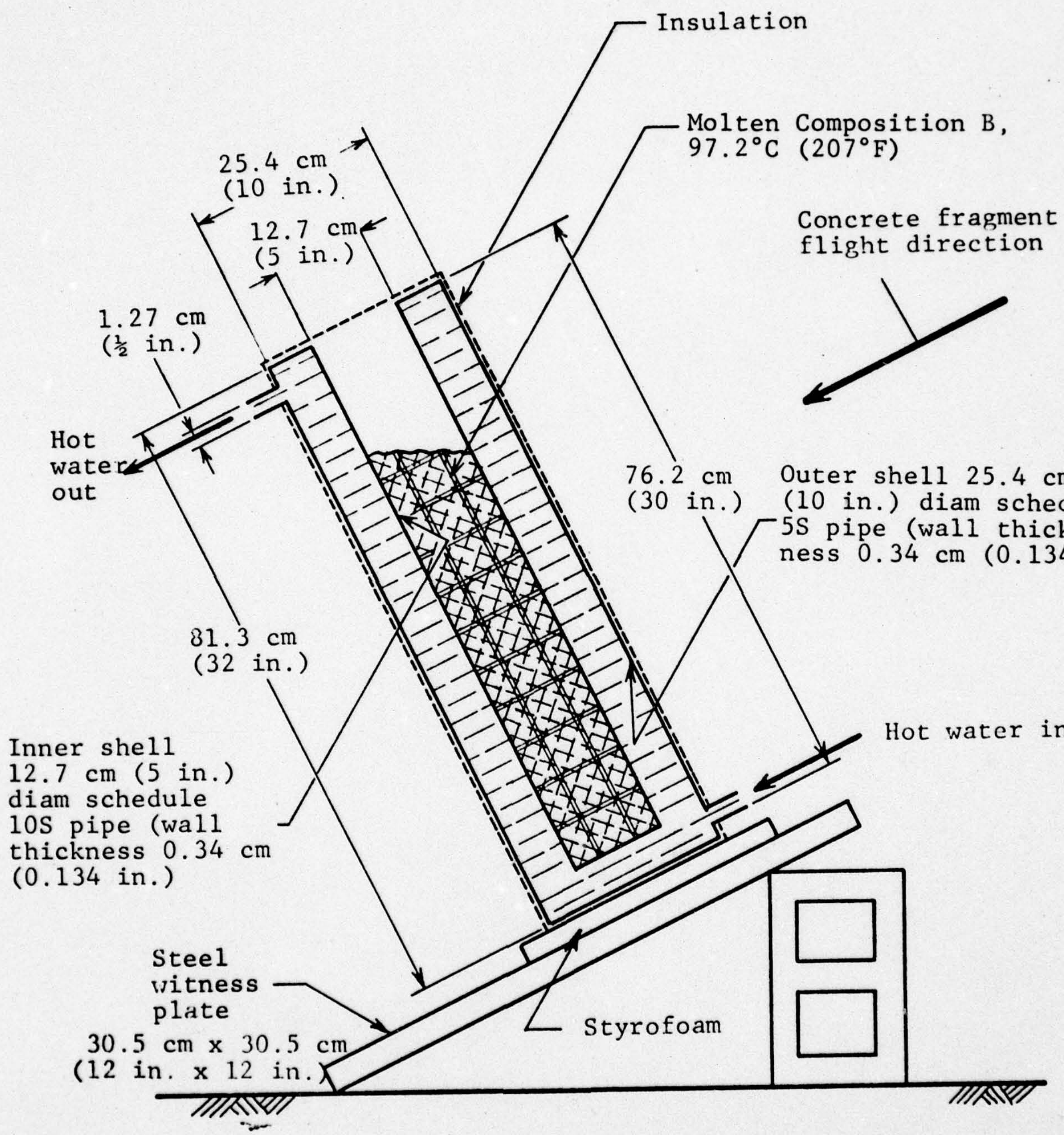


Fig 7 Simulated melt kettle configuration

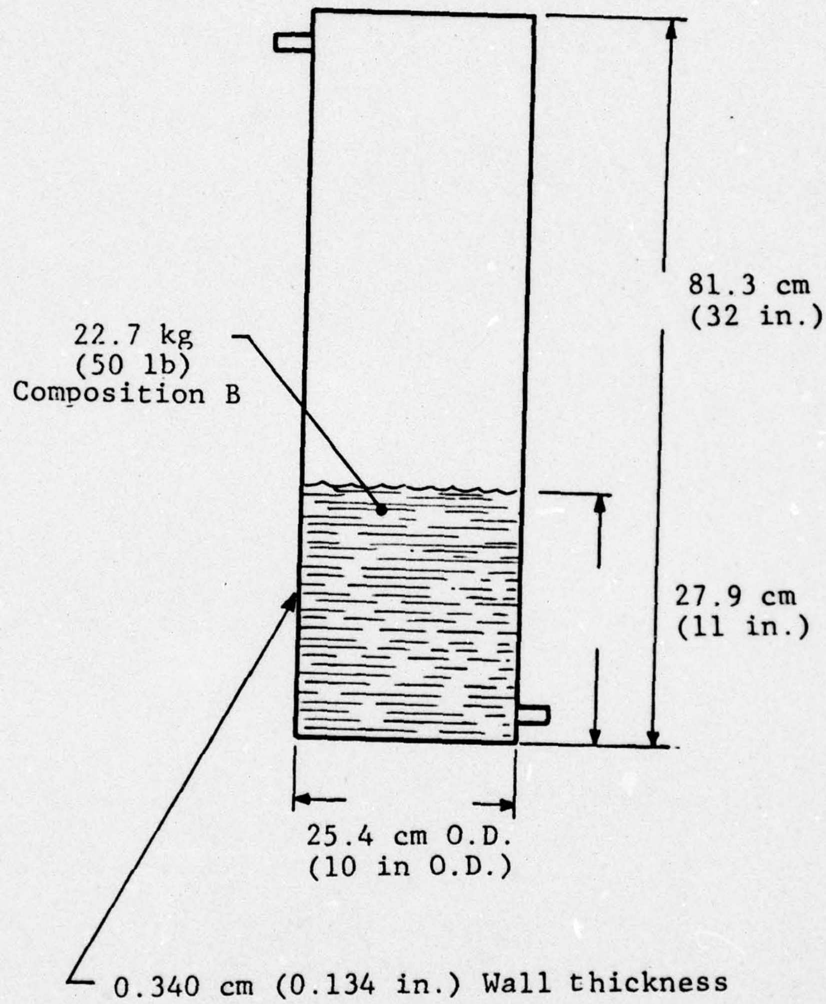


Fig 8 Modified model of melt kettle

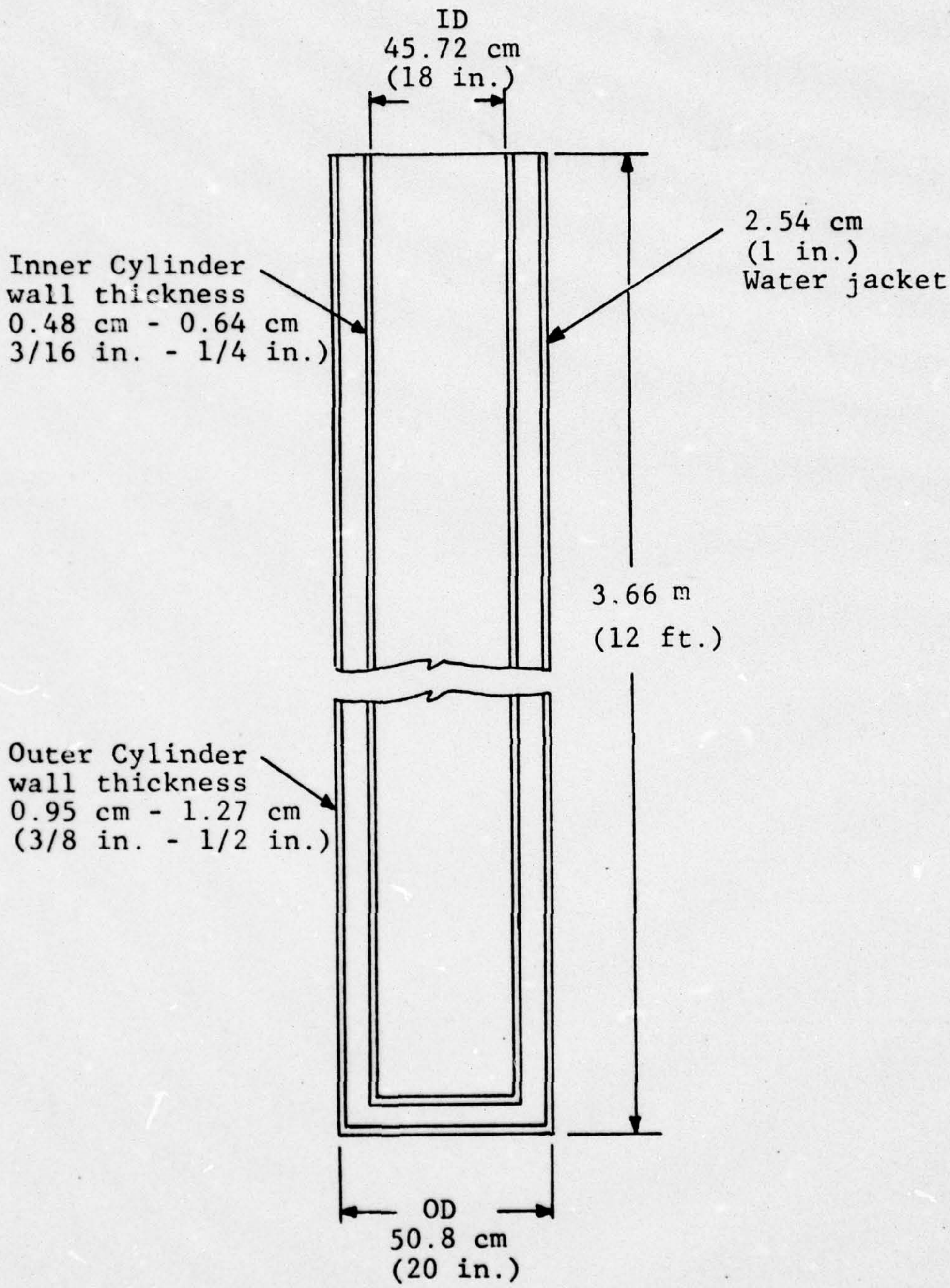


Fig 9 Actual melt kettle

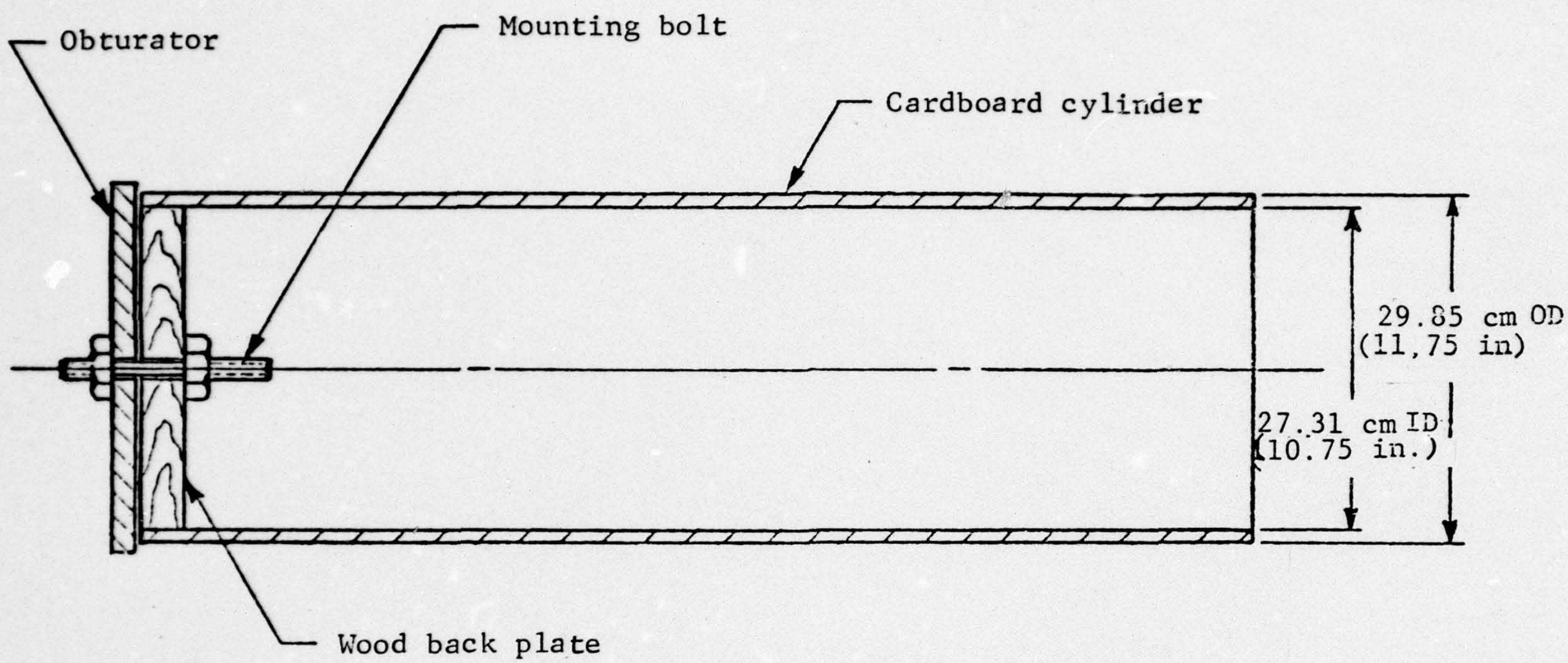


Fig 10 Concrete fragment container

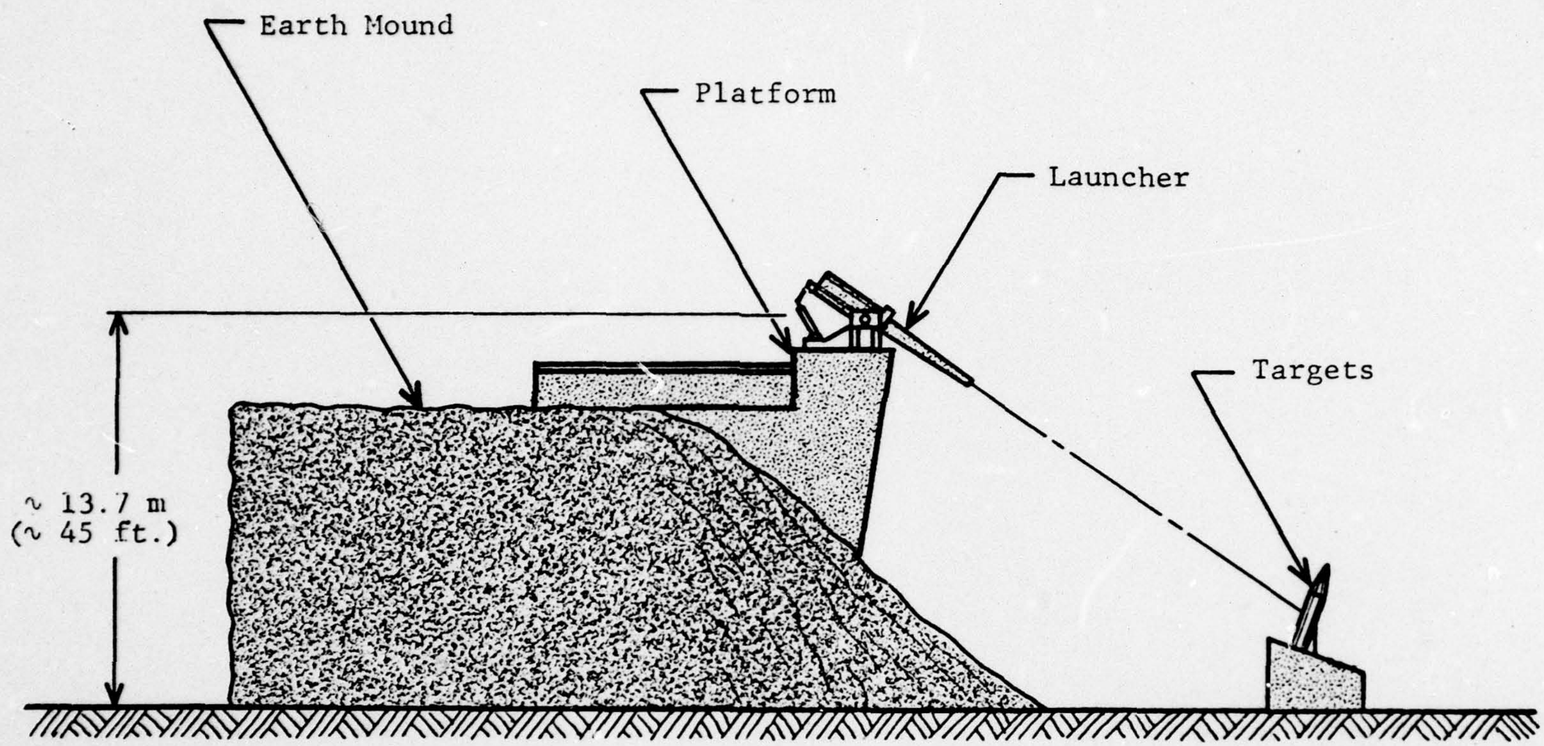


Fig 11 Secondary fragments impact test site

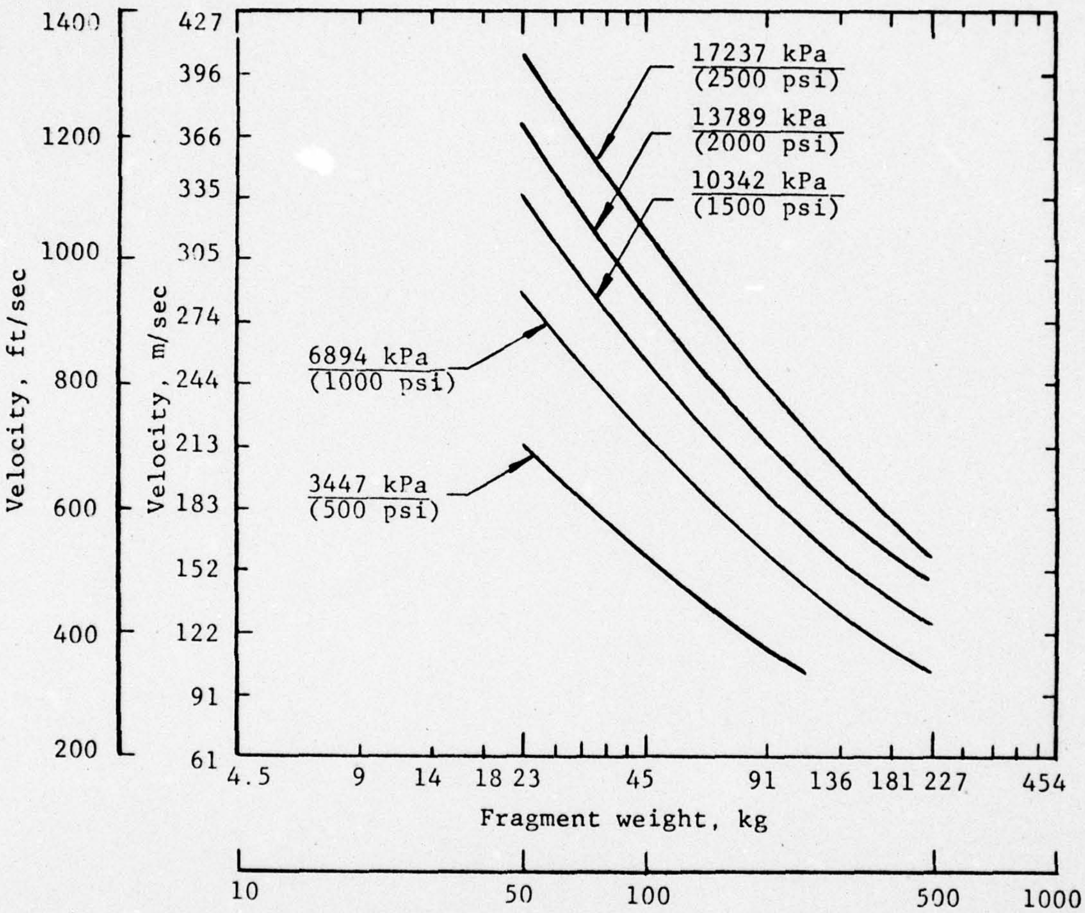


Fig 12 Air gun capability

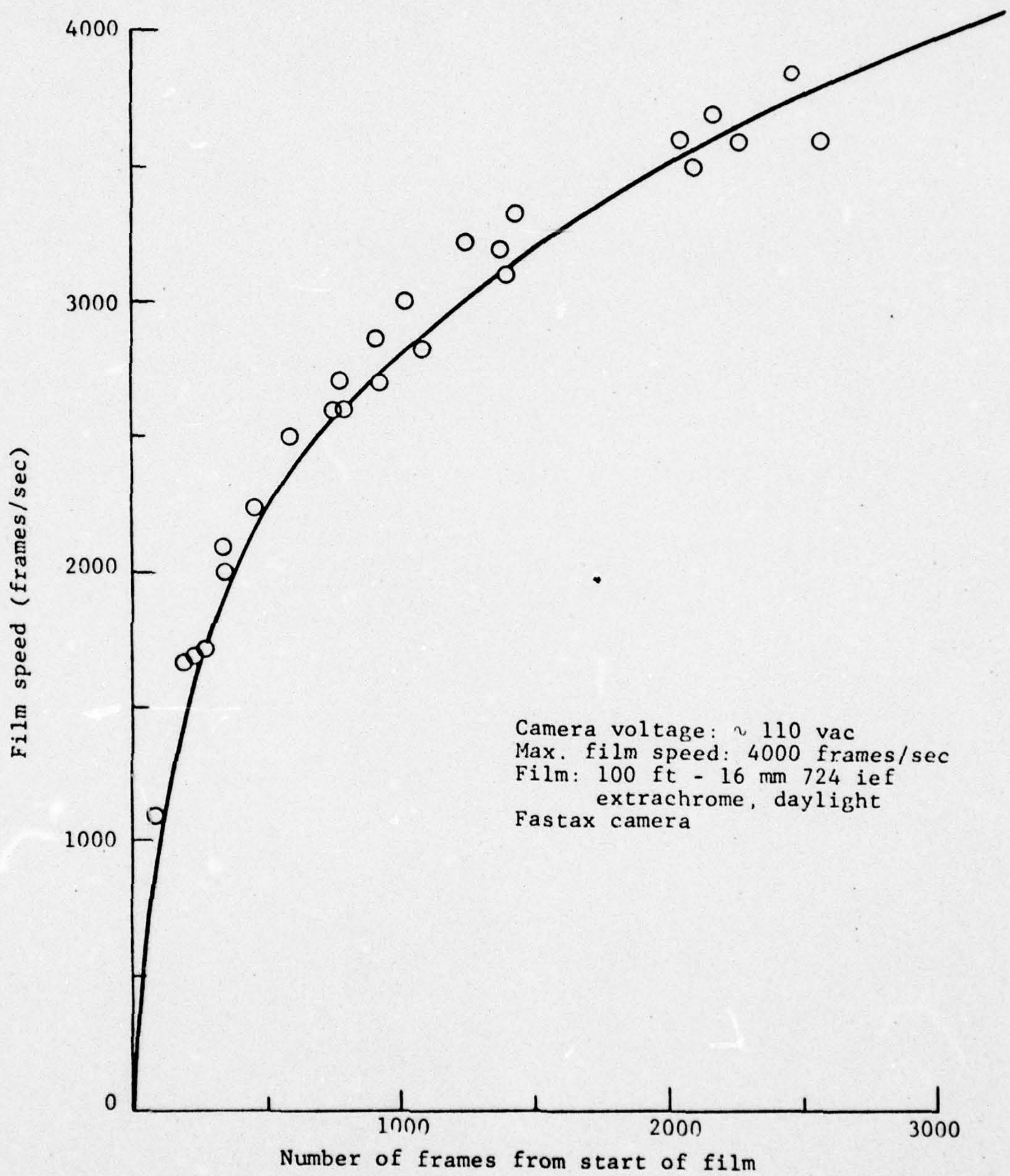


Fig 13 Fastax camera characteristics

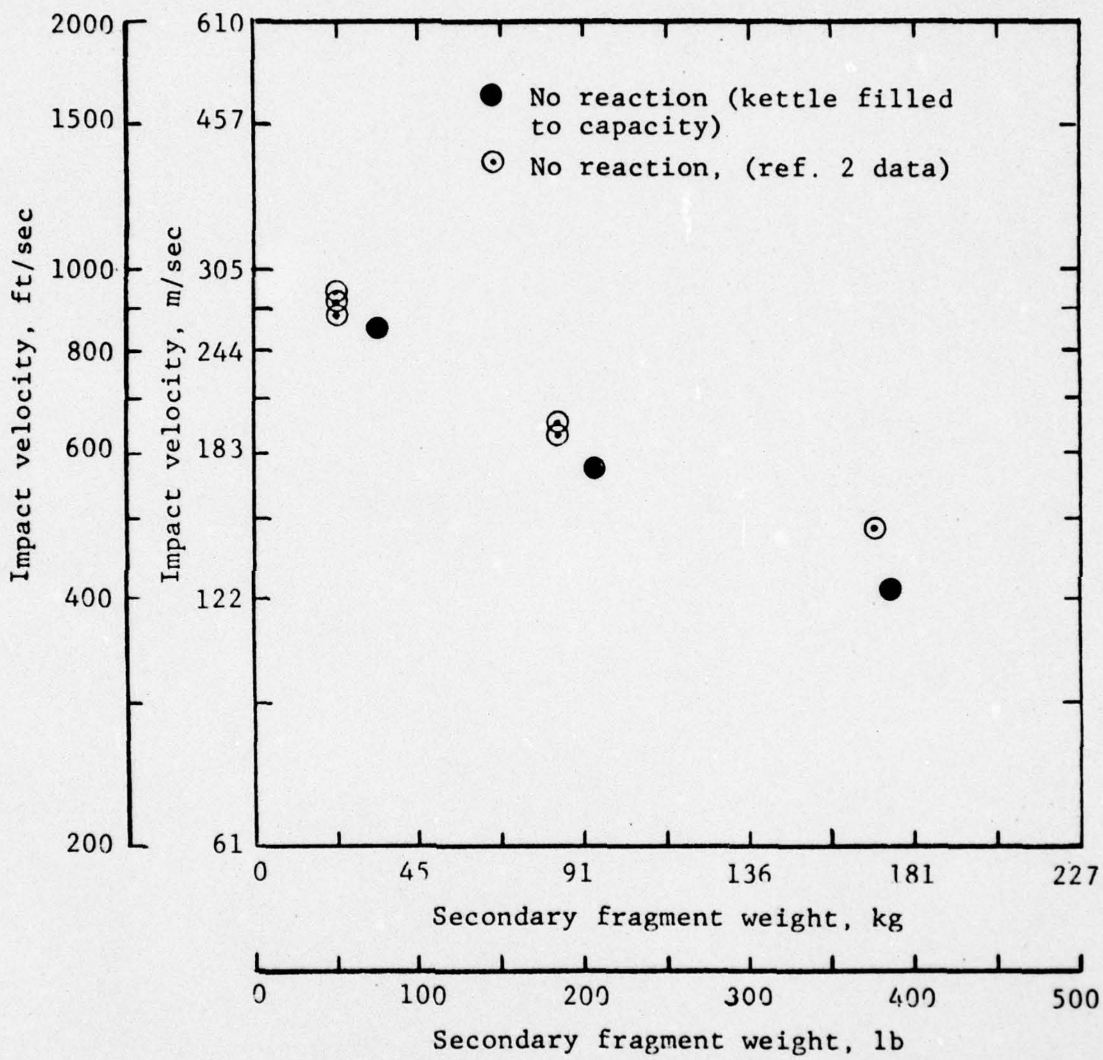


Fig 14 Secondary fragment impact results for scaled model of continuous melt kettle filled with Composition B at 88-97°C (190-207°F). Data in Appendix, tables 1 and 2.

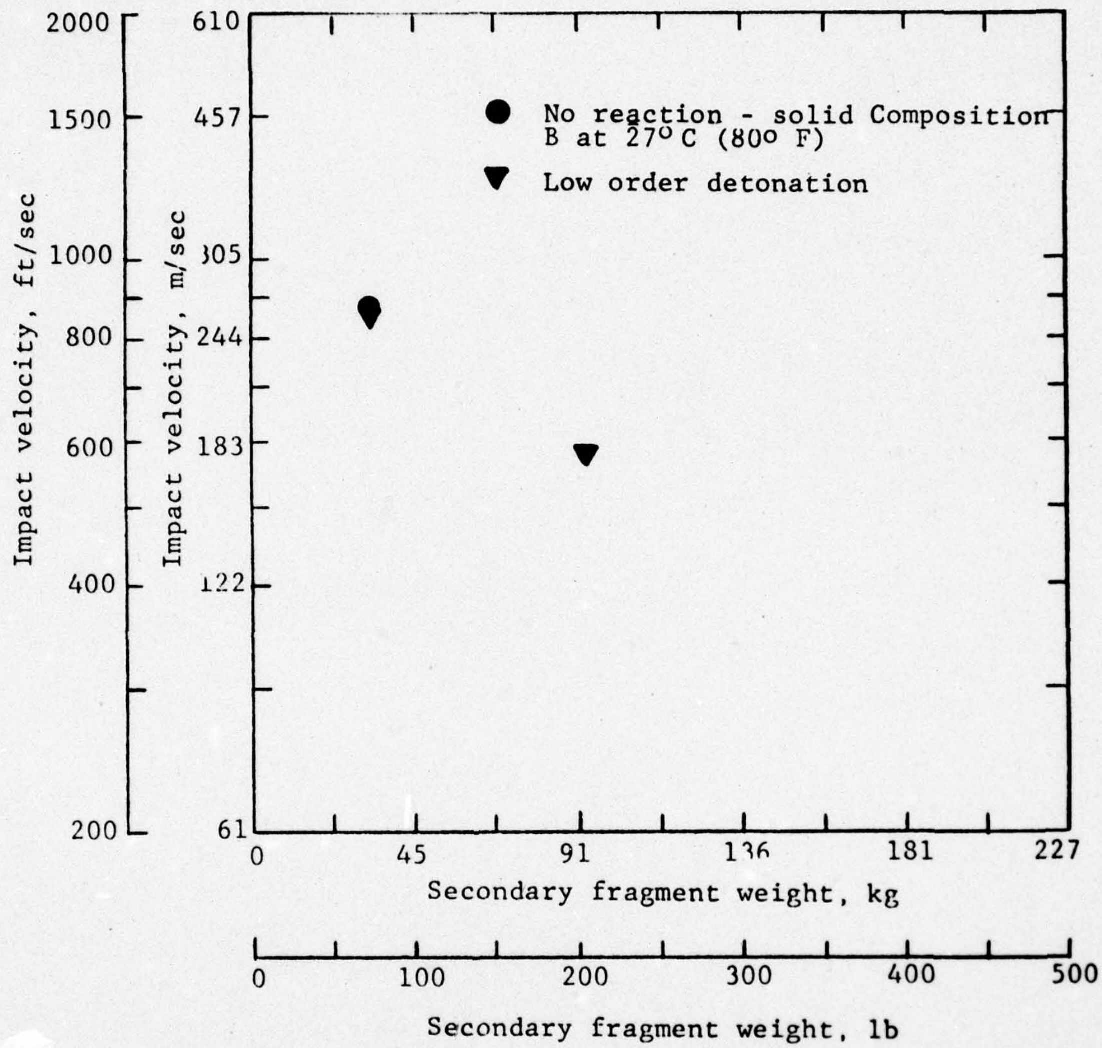


Fig 15 Secondary fragment impact results for modified scaled model of continuous melt kettle filled with Composition B at 77-97°C (170-207°F). Data in Appendix, table 3.

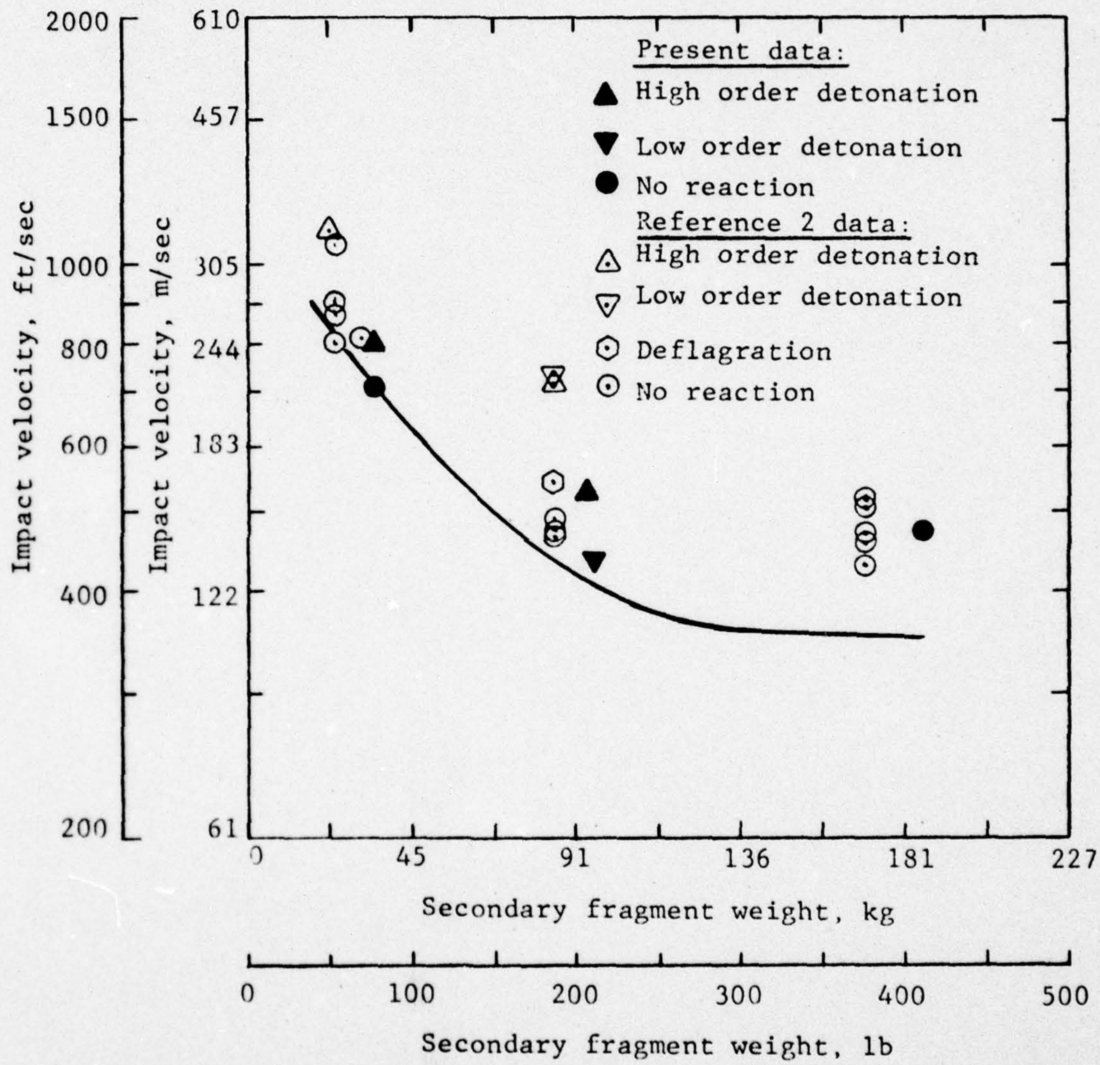


Fig 16 Secondary fragment impact results for 155 mm (M107A1) Howitzer shell, "just filled" condition with Composition B at 77-88°C (170-190°F). Data in Appendix, tables 4 and 5.

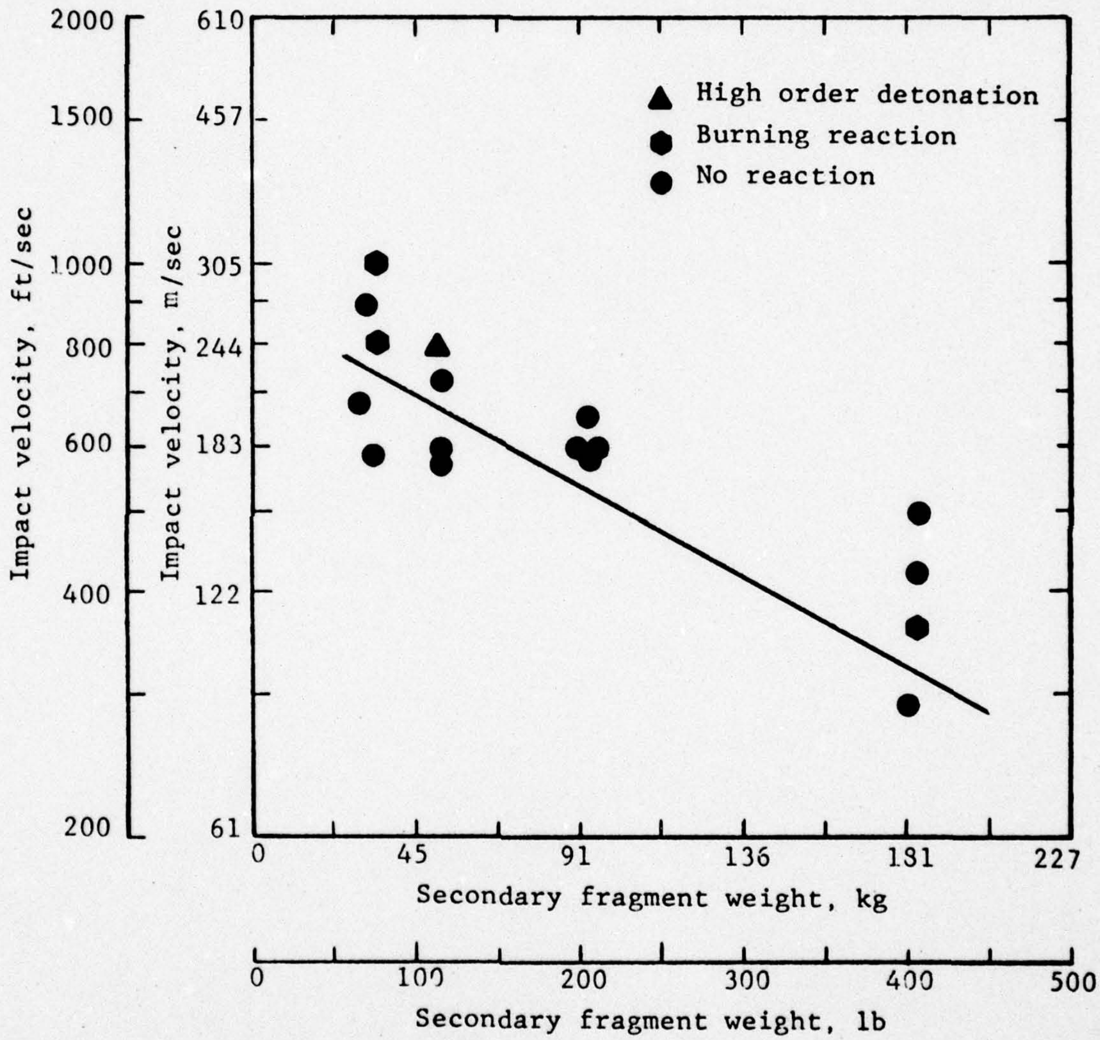


Fig 17 Secondary fragment impact results for 120 mm M356 (T15E2) cannon shell, "just filled" condition with Composition B at 71-82°C (160-180°F). Data in Appendix, table 6.

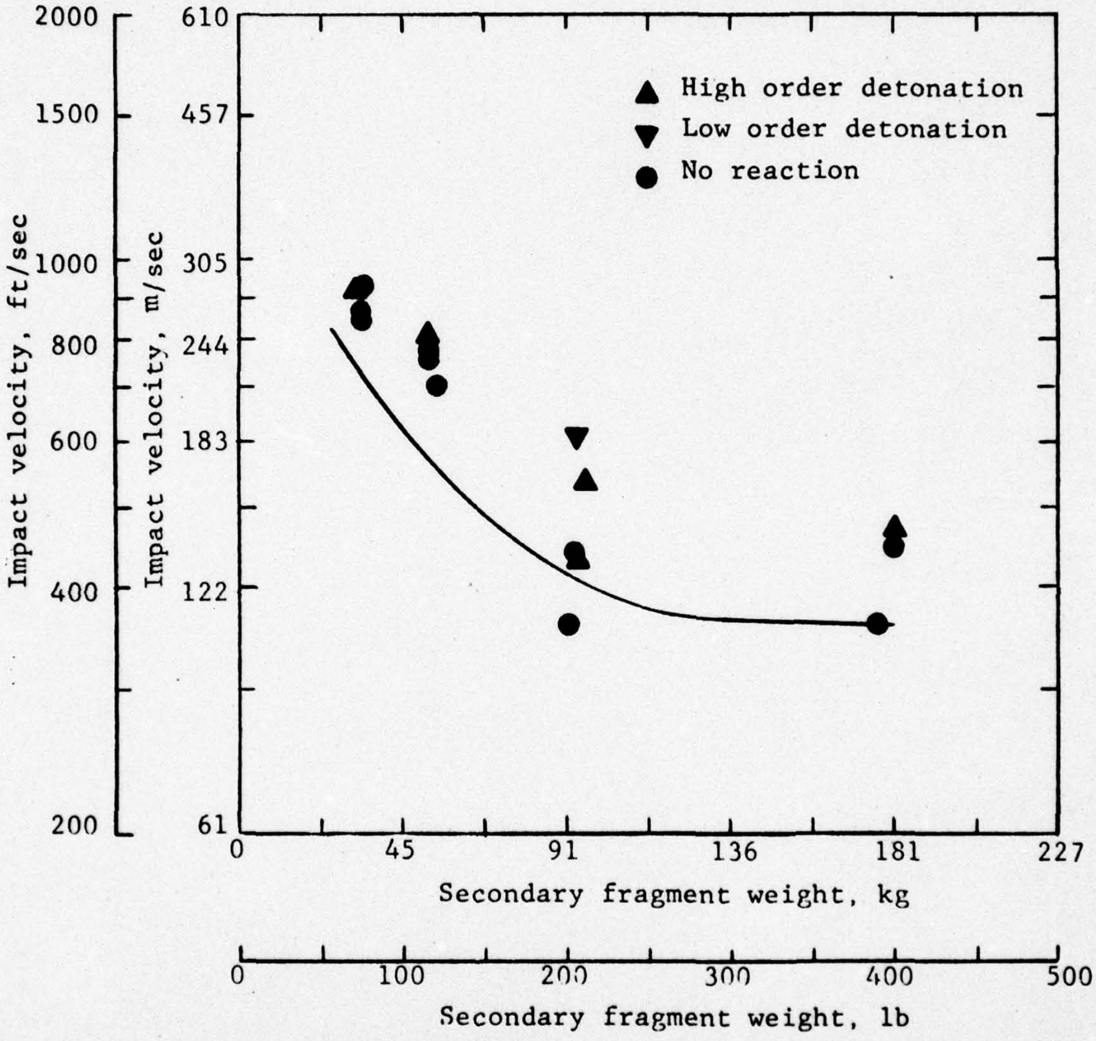


Fig 18 Secondary fragment impact results for 81 mm (M362A1) mortar shell, "just filled" condition with Composition B at 64-88°C (148-190°F). Data in Appendix, table 7.

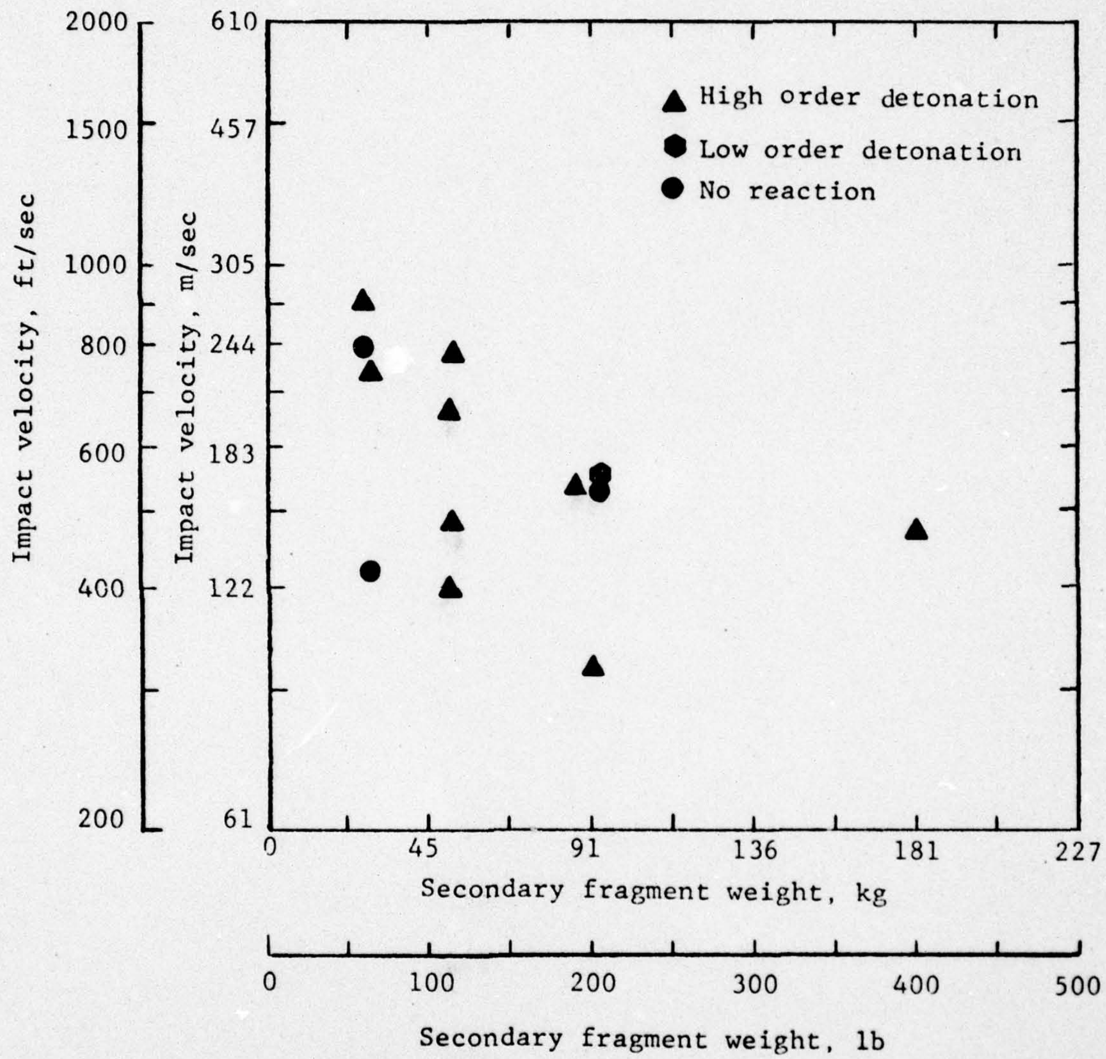


Fig 19 Secondary fragment impact results for 4.2 inch (M329A1) mortar shell, "just filled" condition with TNT at 74-82°C (166-180°F) Data in Appendix, Table 8.

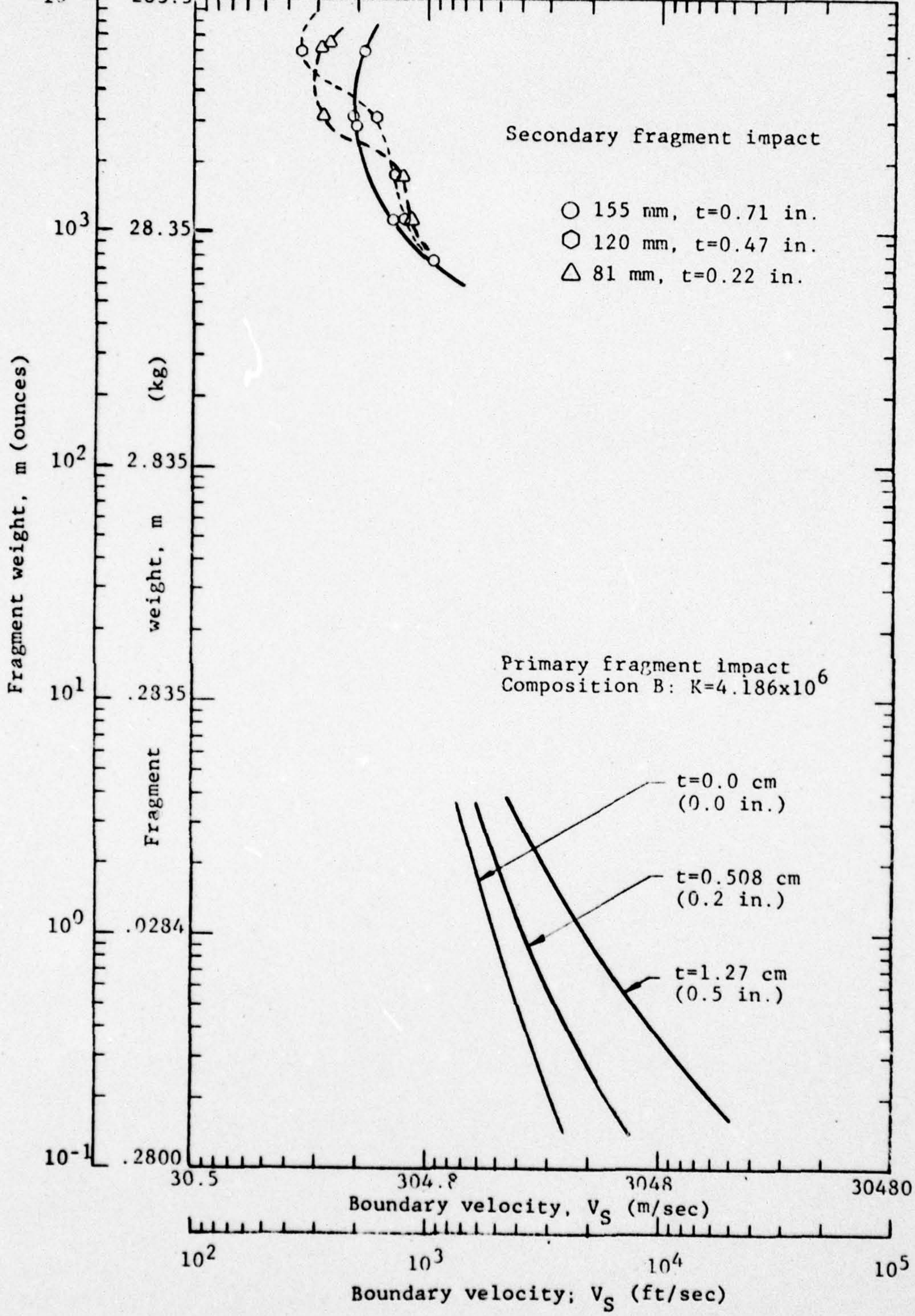


Fig 20 Threshold initiation conditions for primary and secondary fragment impact for various wall casing thickness

APPENDIX

SUMMARY OF EXPERIMENTAL DATA

Table 1

Melt kettle filled with Composition B test series data

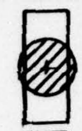
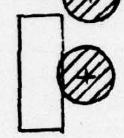
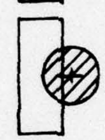
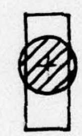
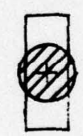
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location	Result
MKL-1	5-26-76	13790 kPa (2000 psi)	~93°C (~200°F)	175 kg (385 lb)	123 m/sec (404 ft/sec)		No reaction: inner and outer cylinder crushed
MKS-1	6-2-76	13790 kPa (2000 psi)	~88°C (~190°F)	23 kg (50 lb) L/D=1/2	257 m/sec (844 ft/sec)		No reaction: minor damage to outer cylinder only (not shown in Fig. 14)
MKM-1	6-3-76	13790 kPa (2000 psi)	~88°C (~190°F)	82 kg (180 lb) L/D=2	172 m/sec (565 ft/sec)		No reaction: minor damage to outer cylinder only (not shown in Fig. 14)
MKS-2	6-29-76	13790 kPa (2000 psi)	~88°C (~190°F)	34 kg (75 lb) L/D=1/2	237 m/sec (777 ft/sec)		No reaction: outer cylinder torn away: small dent on inner cylinder (not shown in Fig. 14)
MKM-2	7-6-76	13790 kPa (2000 psi)	~88°C (~190°F)	93 kg (205 lb) L/D=2	176 m/sec (577 ft/sec		No reaction: inner and outer cylinder crushed
MKS-3	7-8-76	13790 kPa (2000 psi)	~88°C (~190°F)	33 kg (73 lb) L/D=1/2	259 m/sec (851 ft/sec)		No reaction: inner and outer cylinder crushed (spark on impact)

Table 2

Continuous melt kettle filled with Composition B test series data
(Reference 2)

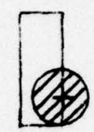
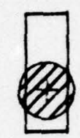
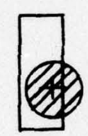
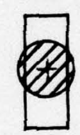
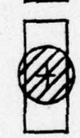
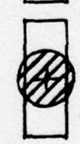
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location	Result
MCS-1	10-9-75	13790 kPa (2000 psi)	97±1°C (207±2°F)	23 kg (50 lb)	287 m/sec (943 ft/sec)		No reaction: approximately 25.4 cm (10 inches) of the outer shell peeled open
MCS-2	10-15-75	13790 kPa (2000 psi)	97±1°C (207±2°F)	23 kg (50 lb)	279 m/sec (914 ft/sec		No reaction: both inner and outer shells crushed open
MCS-3	10-17-75	13790 kPa (2000 psi)	97±1°C (207±2°F)	23 kg (50 lb)	268 m/sec (879 ft/sec)		No reaction: both inner and outer shells severely crushed
MCM-1	10-10-75	13790 kPa (2000 psi)	97±1°C (207±2°F)	84 kg (185 lb)	199 m/sec (652 ft/sec)		No reaction: both inner and outer shells severely crushed
MCM-2	10-16-75	13790 kPa (2000 psi)	97±1°C (207±2°F)	84 kg (185 lb)	191 m/sec (627 ft/sec)		No reaction: both inner and outer shells severely crushed
MCL-1	10-13-75	13790 kPa (2000 psi)	97±1°C (207±2°F)	170 kg (375 lb)	148 m/sec (485 ft/sec)		No reaction: both inner and outer shells severely crushed

Table 3

Modified melt kettle filled with Composition B test series data

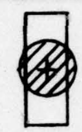
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location	Results
MMS-1	7-16-76	13790 kPa (2000 psi)	27°C (80°F)	34 kg (75 lb) L/D=1/2	267 m/sec (875 ft/sec		No reaction: cylinder severed
MMS-2	7-19-76	13790 kPa (2000 psi)	98°C (208°F)	34 kg (75 lb) L/D=1/2	262 m/sec (859 ft/sec)		Low order detonation
MMM-1	7-27-76	13858 kPa (2010 psi)	77°C (170°F)	93 kg (205 lb) L/D=2	173 m/sec (569 ft/sec)		Low order detonation

Table 4

155 mm (M107A1) Howitzer shell filled with Composition B test series data

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location (2, 1)	Results: Target 1	Results: Target 2
155S-1	8-18-76	12135 kPa (1760 psi)	80-83°C (176-181°F)	34 kg (75 lb) L/D=1/2	244 m/sec (802 ft/sec)		High order detonation	Low order detonation
155S-2	8-19-76	8446 kPa (1225 psi)	81-83°C (178-181°F)	34 kg (75 lb) L/D=1/2	216 m/sec (708 ft/sec)		No reaction: Funnel sheared off, no shell damage	No reaction: no funnel or shell damage
155M-1	8-20-76	8274 kPa (1200 psi)	85-88°C (185-190°F)	93 kg (205 lb) L/D=2	~161 m/sec (~529 ft/sec)		High order detonation	Low order detonation
155M-2	8-24-76	600 kPa (870 psi)	84-87°C (183-189°F)	95 kg (210 lb) L/D=2	~133 m/sec (~435 ft/sec)		Low order detonation	No reaction; scratches on shell
155L-1	8-26-76	14203 kPa (2060 psi)	77-86 C (171-187°F)	186 kg (410 lb) L/D=4	145 m/sec (475 ft/sec)		No reaction: funnel sheared off, no shell damage	No reaction: no damage to shell or funnel
155L-2	8-30-76	13996 kPa (2030 psi)	77-82°C (171-180°F)	186 kg (410 lb) L/D=4	145 m/sec (476 ft/sec)		No reaction: top of shell squeezed shut	No reaction: top of shell squeezed shut

Table 5

155 mm Howitzer shell "just filled" with Composition B test series data
(Reference 2)

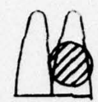
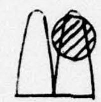
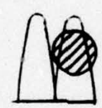
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Target 2
JS-1	10-11-74	13,790 kPa (2000 psi)	82°C (180°F)	32 kg (70 lb)	249 m/sec (818 ft/sec)		No reaction: ~0.32 cm (~1/8 *in.*) *deep* smooth dent, ~8 cm (~3 in.) above rotating band	No reaction: scratches on the *surface*, ~8 *cm* (~3 in.) above rotating band
JM-1	10-17-74	13,790 kPa (2000 psi)	82°C (180°F)	84 kg (185 lb)	224 m/sec (736 ft/sec)		Low order detonation, large fragment, approximately into 3 equal pieces posttest, slight bend on *witness plate* immediately under	No reaction: scratches on surface, ~23 cm (~9 in.) below the top
JL-1	10-26-74	13,790 kPa (2000 psi)	82°C (180°F)	170 kg (375 lb)	154 m/sec (504 ft/sec)		Flash of black smoke, possible smouldering, top squeezed	Not applicable
JS-2	5-02-75	15,518 kPa (2250 psi)	93°C (200°F)	23 kg (50 lb)	~335 m/sec (~1100 ft/sec)		High order detonation, small fragments posttest, severe damage on witness plate immediately under	High order detonation, small fragments posttest, not as severe damage on witness plate immediately under
JS-3	5-05-75	15,168 kPa (2200 psi)	91°C (195°F)	23 kg (50 lb)	~335 m/sec (~1100 ft/sec)		High order detonation, small fragments posttest, clear imprint of base on witness plate immediately under, severe bending of witness plate immediately under	Low order detonation, large fragments, but less than 30 cm (12 in.) long, posttest, slight imprint of base on witness plate immediately under

Table 5 (Contd)

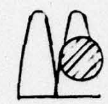
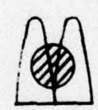
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
JM-2	5-06-75	14,478 kPa (2100 psi)	93°C (200°F)	84 kg (185 lb)	~219 m/sec (~720 ft/sec)		High order detonation, small fragments posttest, clear imprint of base on witness plate, bending of witness plate immediately under	Low order detonation, large piece of fragments, whole length of the target, scratches ~20 cm (~8 in.) below to
JL-2	5-29-75	14,478 kPa (2100 psi)	93°C (200°F)	170 kg (375 lb)	140 m/sec (460 ft/sec)		No reaction: sharp and deep dent, ~23 cm (~9 in.) below top	No reaction: scratches ~23 cm (~9 in.) below tc
JM-3	5-30-75	6,549 kPa (950 psi)	96°C (205°F)	84 kg (185 lb)	166 m/sec (546 ft/sec)		Deflagaration, target fragmented into 3 equal pieces, unburnt Comp B in base posttest, bending of witness plate immediately under	No reaction; unburnt Comp B in shell, scratches on surface, ~18 c (~7 in.) below tc
JL-3	6-03-75	8,963 kPa (1300 psi)	96°C (205°F)	170 kg (375 lb)	132 m/sec (432 ft/sec)		No reaction: dent and slight squeezing on upper 1/4 of target	No reaction: no damage
JM-4	10-22-75	6,549 kPa (950 psi)	93°C (200°F)	84 kg (185 lb)	141 m/sec (465 ft/sec)		No reaction: smooth dent, ~15 cm (~6 in.) above rotating band	No reaction: scratches on surface, ~15 cm (~6 in.) above rotating band
JM-5	10-23-75	6,549 kPa (950 psi)	93°C (200°F)	84 kg (185 lb)	144 m/sec (472 ft/sec)		No reaction: slight and smooth dent, ~18 cm (~7 in.) above rotating band	No reaction: slight and smooth dent, ~18 cm (~7 in.) above rotating band

Table 5 (concl)

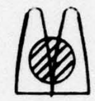
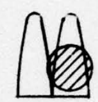
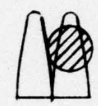
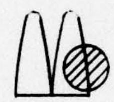
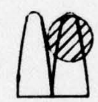
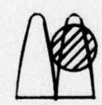
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
JM-6	10-24-75	6,549 kPa (950 psi)	93°C (200°F)	84 kg (185 lb)	150 m/sec (490 ft/sec)		No reaction: slight dent, ~13 cm (~5 in.) above rotating band	No reaction: scratches on surface, ~13 cm (~5 in.) above rotating band
JS-4	10-27-75	8,790 kPa (1275 psi)	92°C (197°F)	24 kg (52 lb)	244 m/sec (800 ft/sec)		No reaction: ~1 cm (~1/2 in.) deep smooth dent, ~11 cm (~4-1/2 in.) above rotating band	No reaction: ~1 cm (~1/2 in.) deep smooth dent, ~11 cm (~4-1/2 in.) above rotating band
JS-5	10-28-75	13,789 kPa (2000 psi)	92°C (197°F)	24 kg (52 lb)	274 m/sec (900 ft/sec)		No reaction: slight, smooth dent around rotating band	No reaction: scratches on surface around rotating band
JS-6	10-30-75	13,789 kPa (2000 psi)	89°C (193°F)	24 kg (52 lb)	265 m/sec (869 ft/sec)		No reaction: deep sharp dent in middle, slight bending of whole target	No reaction: scratches on surface around rotating band
JS-7	11-03-75	15,513 kPa (2250 psi)	86°C (187°F)	24 kg (52 lb)	325 m/sec (1065 ft/sec)		No reaction: glancing hit, scratches on surface, ~15 cm (~6 in.) above rotating band	No reaction: no damage
JL-4	11-04-75	15,513 kPa (2250 psi)	86°C (187°F)	170 kg (375 lb)	159 m/sec (520 ft/sec)		No reaction: shallow dent ~18 cm (~7 in.) below top	No reaction: scratches on surface ~18 cm (~7 in.) below top
JL-5	11-05-75	15,513 kPa (2250 psi)	86°C (187°F)	170 kg (375 lb)	143 m/sec (470 ft/sec)		No reaction: smooth and deep dent, ~1 cm (~1/2 in.) deep, ~18 cm (~7 in.) below top	No reaction: scratches

Table 6

120 mm (T15E2, M356) cannon projectile "just filled" with Composition B test series data

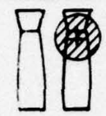
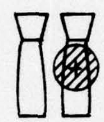
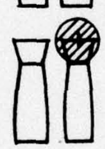
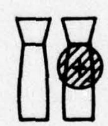
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Results Target 2
120S-1	9-24-76	14,548 kPa (2110 psi)	81°C (178°F)	32 kg (71 lb) L/D = 1/2	269 m/sec (882 ft/sec)		No reaction: top of shell and funnel crushed	No reaction: no damage to shell or funnel
120MS-1	9-28-76	14,755 kPa (2140 psi)	77-78°C (171-172°F)	51 kg (112 lb) L/D = 1	243 m/sec (797 ft/sec)		High order reaction	No reaction: no shell or funnel damage
120L-1	9-29-76	16,285 kPa (2362 psi)	77-81°C (171-178°F)	184 kg (406 lb) L/D = 4	149 m/sec (489 ft/sec)		No reaction: funnel destroyed, top of shell squeezed shut	No reaction: funnel broke off, scratches on shell
120S-2	9-30-76	16,706 kPa (2423 psi)	81°C (178°F)	34 kg (75 lb) L/D = 1/2	301 m/sec (988 ft/sec)		Burning reaction: shell broke in half	No reaction: funnel dented, no shell damage
120M-1	10-04-76	14,169 kPa (2055 psi)	72-75°C (162-167°F)	93 kg (205 lb) L/D = 2	~176 m/sec (~576 ft/sec)		No reaction: funnel destroyed, top of shell squeezed shut	No reaction: funnel dented, no damage to shell
120MS-2	10-05-76	6,895 kPa (1000 psi)	72-78°C (162-172°F)	52 kg (115 lb) L/D = 1	173 m/sec (568 ft/sec)		No reaction: funnel sheared off, no damage to shell	No reaction: no damage to funnel or shell
120MS-3	10-06-76	6,895 kPa (1000 psi)	74-78°C (165-172°F)	52 kg (115 lb) L/D = 1	182 m/sec (596 ft/sec)		No reaction: funnel broke off, shell slightly dented	No reaction: no damage to funnel, scratches on side of shell

Table 6 (Contd)

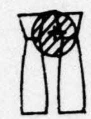
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
120M-2	10-07-76	14,893 kPa (2160 psi)	73°C (163°F)	95 kg (209 lb) L/D = 2	180 m/sec (591 ft/sec)		No reaction: funnel broke off, shell slightly dented	No reaction: no damage to funnel or shell
120MS-4	10-11-76	11,307 kPa (1640 psi)	73°C (163°F)	52 kg (115 lb) L/D = 1	220 m/sec (721 ft/sec)		No reaction: funnel destroyed, top of shell squeezed shut	No reaction: funnel destroyed, top of shell scratched
120M-3	10-12-76	15,168 kPa (2200 psi)	78-79°C (172-174°F)	93 kg (205 lb) L/D = 2	199 m/sec (652 ft/sec)		No reaction: funnel destroyed, top of shell squeezed shut	No reaction: no damage to funnel or shell
120L-2	10-13-76	15,168 kPa (2200 psi)	79°C (174°F)	184 kg (406 lb) L/D = 4	~109 m/sec (~358 ft/sec)		Burning reaction: funnel destroyed, shell broke in half, bottom left intact	
120L-3	10-20-76	11,101 kPa (1610 psi)	80°C (176°F)	181 kg (400 lb) L/D = 4	~88 m/sec (~288 ft/sec)		No reaction: funnel destroyed, top of shell squeezed	
120M-4	10-22-76	15,506 kPa (2249 psi)	83°C (181°F)	89 kg (197 lb) L/D = 2	182 m/sec (596 ft/sec)		No reaction: funnel destroyed, shell slightly dented	
120S-3	10-26-76	11,032 kPa (1600 psi)	79°C (174°F)	34 kg (75 lb) L/D = 1/2	~244 m/sec (~800 ft/sec)		Burning reaction: no shell damage, wooden stand charred	

Table 6 (Concl)

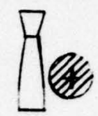
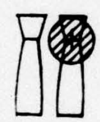
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results: Target 1	Results: Target 2
120S-4	10-29-76	6,895 kPa (100 psi)	80°C (176°F)	33 kg (73 lb) L/D = 1/2	178 m/sec (585 ft/sec)		No damage, gun misaligned (not shown in Fig. 17)	
120S-5	11-02-76	6,895 kPa (1000 psi)	80°C (176°F)	34 kg (75 lb) L/D = 1/2	~178 m/sec (~585 ft/sec)		No reaction: shell dented ~ 2.54 cm (~1 in.) deep, funnel broken off	
120S-6	05-04-77	12,631 kPa (1832 psi)	81°C (178°F)	30 kg (66 lb) L/D = 1/2	~207 m/sec (~679 ft/sec)		No reaction: funnel sheared off, no damage to shell	No reaction: no damage to funnel or shell
120L-4	05-05-77	12,548 kPa (1820 psi)	77°C (171°F)	184 kg (405 lb) L/D = 4	~129 m/sec (~422 ft/sec)		No reaction: funnel destroyed, shell squeezed shut	No reaction: funnel destroyed, no shell damage

Table 7

81 mm (M362A1) mortar shell "just filled" with Composition B test series data

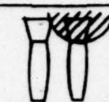
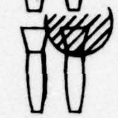
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Results Target 2
81S-1	8-09-76	11,135 Kpa (1615 psi)	44°C (111°F)	34 kg (75 lb) L/D = 1/2	~260 m/sec (~853 ft/sec)		No reaction: funnel sheared off, no damage to shell	No reaction: no damage to funnel or shell
81S-2	8-11-76	13,790 kPa (2000 psi)	44°C (111°F)	33 kg (73 lb) L/D = 1/2	284 m/sec (932 ft/sec)		No reaction: funnel sheared off, no damage to shell	No reaction: funnel sheared off, no damage to shell
81S-3	8-13-76	13,790 kPa (2000 psi)	64°C (147°F)	34 kg (75 lb) L/D = 1/2	262 m/sec (858 ft/sec)		No reaction: only funnel and small metal fragments recovered	No reaction: smal dent on shell, nc damage to funnel
81S-4	9-01-76	14,479 kPa (2100 psi)	71-75°C (160-167°F)	34 kg (75 lb) L/D = 1/2	263 m/sec (864 ft/sec)		No reaction: bottom crushed	No reaction: bottom bent
81MS-1	9-03-76	13,962 kPa (2025 psi)	78-80°C (172-176°F)	52 kg (115 lb) L/D = 1	234 m/sec (768 ft/sec)		No reaction: shell severely crushed	No reaction: no damage to shell or funnel
81M-1	9-08-76	13,927 kPa (2020 psi)	76-78°C (168-172°F)	93 kg (205 lb) L/D = 2	186 m/sec (611 ft/sec)		Low order reaction	High order reaction
81MS-2	9-13-76	14,651 kPa (2125 psi)	81-88°C (177-190°F)	54 kg (120 lb) L/D = 1	214 m/sec (703 ft/sec)		No reaction: top of shell squeezed shut	No reaction: funnel destroyed, nc shell damage
81M-2	9-14-76	8,618 kPa (1250 psi)	76°C (168°F)	95 kg (210 lb) L/D = 2	163 m/sec (535 ft/sec)		High order reaction	Possible sympathetic high order reaction
81S-5	9-15-76	14,341 kPa (2080 psi)	75-76°C (166-168°F)	32 kg (70 lb) L/D = 1/2	276 m/sec (906 ft/sec)		High order reaction	No reaction: funnel destroyed, to of shell crushed
81M-3	9-16-76	4,826 kPa (700 psi)	77-82°C (170-179°F)	93 kg (205 lb) L/D = 2	134 m/sec (440 ft/sec)		No reaction: shell severely crushed	No reaction: no shell or funnel damage

Table 7 (Concl)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1	Target 2
81MS-3	9-17-76	13,603 kPa (1973 psi)	68-83°C (155-181°F)	52 kg (115 lb) L/D = 1	248 m/sec (813 ft/sec)		High order reaction	No reaction: no shell damage, f nel bent at nec
81-L-1	9-21-76	14,582 kPa (2115 psi)	78-79°C (173-175°F)	181 kg (400 lb) L/D = 4	137 m/sec (449 ft/sec)		No reaction: funnel crushed	No reaction: fu nel dented
81M-4	9-22-76	6,205 kPa (900 psi)	82°C (179°F)	93 kg (205 lb) L/D = 2	133 m/sec (435 ft/sec)		High order reaction	No reaction: no damage to shell or funnel
81MS-4	9-23-76	13,031 kPa (1890 psi)	78-79°C (172-174°F)	52 kg (115 lb) L/D = 1	232 m/sec (760 ft/sec)		No reaction: funnel and top of shell crushed	No reaction: fu nel dented
81M-5	10-14-76	4,268 kPa (619 psi)	67-72°C (152-162°F)	91 kg (200 lb) L/D = 2	109 m/sec (358 ft/sec)		No reaction: funnel flattened, shell squeezed shut	No reaction: nc damage to shell
81L-2	10-15-76	15,237 kPa (2210 psi)	77°C (171°F)	184 kg (405 lb) L/D = 4	~117 m/sec (~383 ft/sec)		High order reaction: funnel only slightly dented	No reaction: sn scratch on shel
81L-3	10-18-76	8,287 kPa (1201 psi)	74-79°C (166-175°F)	177 kg (390 lb) L/D = 4	109 m/sec (359 ft/sec)		No reaction: funnel and shell crushed	No reaction: nc damage
81L-4	4-20-77	13,445 kPa (1950 psi)	70°C (158°F)	181 kg (400 lb) L/D = 4	139 m/sec (457 ft/sec)		No reaction: funnel and shell slightly damaged	No reaction: nc damage

Table 8

4.2 inch (M329A1) mortar shell "just filled" with TNT test series data

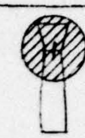
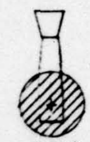
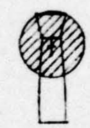
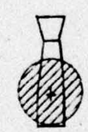
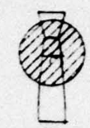
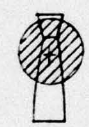
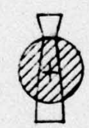
Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1
4.2S-1	05-10-77	14,479 kPa (2100 psi)	77°C (171°F)	27 kg (60 lb) L/D = 1/2	~273 m/sec (~896 ft/sec)		High order detonation
4.2S-2	05-11-77	9,653 kPa (1400 psi)	80°C (176°F)	27 kg (60 lb) L/D = 1/2	242 m/sec (793 ft/sec)		No reaction: shell severely flattened
4.2MS-1	05-12-77	14,479 kPa (2100 psi)	77°C (171°F)	52 kg (115 lb) L/D = 1	~236 m/sec (~774 ft/sec)		High order detonation
4.2MS-2	05-13-77	9,997 kPa (1450 psi)	79°C (174°F)	51 kg (112 lb) L/D = 1	201 m/sec (659 ft/sec)		High order detonation
4.2M-1	05-17-77	14,479 kPa (2100 psi)	81°C (178°F)	93 kg (205 lb) L/D = 2	160 m/sec (525 ft/sec)		No reaction: top of shell squeezed shut, funnel crushed
4.2M-2	05-18-77	14,479 kPa (2100 psi)	79°C (174°F)	93 kg (205 lb) L/D = 2	168 m/sec (551 ft/sec)		Flash at impact
4.2MS-3	05-19-77	5,516 kPa (800 psi)	79°C (174°F)	51 kg (112 lb) L/D = 1	123 m/sec (404 ft/sec)		High order detonation

Table 8 (Concl)

Test No.	Date	Gun Chamber Pressure	Explosive Temperature	Fragment Size	Fragment Velocity	Hit Location #2 #1	Results Target 1
4.2L-1	05-23-77	14,479 kPa (2100 psi)	79°C (174°F)	182 kg (400 lb) L/D = 2	143 m/sec (470 ft/sec)		High order detonation
4.2M-3	05-24-77	8,274 kPa (1200 psi)	77°C (171°F)	86 kg (190 lb) L/D = 2	161 m/sec (528 ft/sec)		High order detonation
4.2S-3	05-25-77	6,895 kPa (1000 psi)	74°C (165°F)	30 kg (66 lb) L/D = 1/2	226 m/sec (741 ft/sec)		High order detonation
4.2MS-4	05-26-77	4,137 kPa (600 psi)	79°C (174°F)	52 kg (115 lb) L/D = 1	146 m/sec (480 ft/sec)		High order detonation
4.2M-4	06-01-77	2,758 kPa (400 psi)	82°C (180°F)	91 kg (201 lb) L/D = 2	97 m/sec (318 ft/sec)		High order detonation
4.2S-4	06-02-77	1,379 kPa (200 psi)	80°C (176°F)	30 kg (66 lb) L/D = 1/2	127 m/sec (417 ft/sec)		No reaction: shell squeezed flat in middle